TRENDS IN SOUTHEAST ASIA

URBAN BIODIVERSITY AND NATURE-BASED SOLUTIONS IN SOUTHEAST ASIA

Perspectives from Indonesia and Malaysia

Alex M. Lechner, Michelle Li Ern Ang, Juin Yan Ooi, Badrul Azhar, J. Miguel Kanai, Perrine Hamel and Saut Sagala

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FOREWORD

The economic, political, strategic and cultural dynamism in Southeast Asia has gained added relevance in recent years with the spectacular rise of giant economies in East and South Asia. This has drawn greater attention to the region and to the enhanced role it now plays in international relations and global economics.

The sustained effort made by Southeast Asian nations since 1967 towards a peaceful and gradual integration of their economies has had indubitable success, and perhaps as a consequence of this, most of these countries are undergoing deep political and social changes domestically and are constructing innovative solutions to meet new international challenges. Big Power tensions continue to be played out in the neighbourhood despite the tradition of neutrality exercised by the Association of Southeast Asian Nations (ASEAN).

The **Trends in Southeast Asia** series acts as a platform for serious analyses by selected authors who are experts in their fields. It is aimed at encouraging policymakers and scholars to contemplate the diversity and dynamism of this exciting region.

THE EDITORS

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EXECUTIVE SUMMARY

- Rapid urbanization and development in Southeast Asia have impacted its high biodiversity and unique ecosystems, directly through the use of forest lands for infrastructure building, and indirectly through increasing ecological footprints.
- In Greater Bandung, Indonesia and Greater Kuala Lumpur, Malaysia, rapid urbanization over the last thirty years has resulted in an increase in built infrastructure of approximately two and three times respectively.
- A Nature-Based Solutions approach can potentially underpin urban design and planning strategies in Greater Bandung and Greater Kuala Lumpur, as well as other cities in Southeast Asia, to address biodiversity conservation and also global environmental challenges such as climate change adaption and mitigation, while supporting well-being.
- Mainstreaming Nature-Based Solutions in Southeast Asia will require knowledge gaps to be addressed, greater awareness, increasing the evidence base, metrics for measuring success, support from institutions and stakeholders, and new and innovative financing.
- The urgency of global socio-ecological challenges, in particular the biodiversity and climate crisis, means transformational change is needed in Southeast Asia, for urban, ecological, technical, economic, and social systems, while still supporting sustainable development.

Urban Biodiversity and Nature-Based Solutions in Southeast Asia: Perspectives from Indonesia and Malaysia

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1. INTRODUCTION

More people are living in cities than ever before with around 55 per cent of the world's population in cities as of 2018, and this is expected to grow to 68 per cent by 2050 (UN DESA 2018). Much of this rapid urbanization is concentrated in the Global South, such as in low- and middle-income countries, which have all experienced significant increases in population and rural to urban migration (Hajer et al. 2020; UN DESA 2018). By 2050, there is expected to be another 2.5 billion people living in urban

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areas with approximately 90 per cent of this increase taking place in Asia and Africa (UN DESA 2018). Of the urban infrastructure required in 2050, around 40 per cent has yet to be built (Hajer et al. 2020). In the coming decades, Southeast Asia is expected to experience one of the greatest increases in population and urbanization in the world.

Countries in Southeast Asia are rapidly urbanizing from their historically rural population base, with each country at different points in their urbanization development pathway, from Singapore with 100 per cent urbanization to Cambodia with 24.7 per cent urbanization in 2021 (UN DESA 2018). Around 66 per cent of the population of Southeast Asia is expected to reside in urban areas in 2050, compared to an estimated 51 per cent in 2021 and 16 per cent in 1950 (Figure 1a). Of the Southeast Asian nations, Malaysia is one of the most urbanized of the low- and middle-income countries (Lechner et al. 2020a), with an estimated 78 per cent of its population in cities (Figure 1a). Meanwhile, Indonesia, which is a lower-middle-income country (World Bank 2021), has the largest population in Southeast Asia at 271 million (BPS 2021), with an estimated 57 per cent of its population in cities (Figure 1a). Indonesia is also home to the megacity (i.e., city with over 10 million) of Jakarta with a population in Daerah Khusus Ibukota (Capital Special Region) of 11 million (BPS 2021) and upwards of 30 million in the Jakarta metropolitan area (Jabodetabekjur) (BPS 2021). The growth of megacities such as Bangkok and Manila, and major cities approaching megacity size, such as Greater Kuala Lumpur and Ho Chi Minh, is triggering a ripple effect, promoting growth in nearby cities and thereby concentrating urbanization in selected regions (Suzuki 2019).

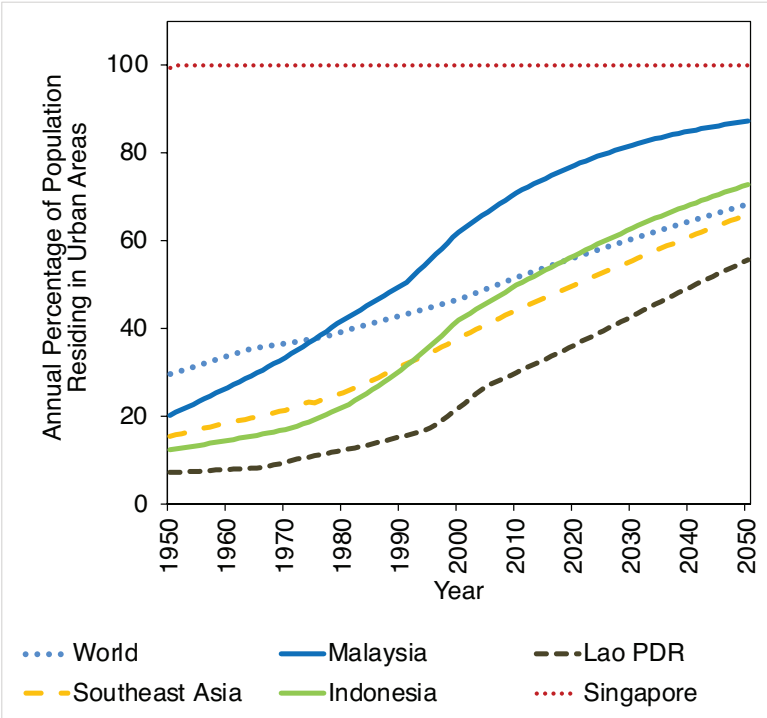
Cities are drivers of economic activity, resource production and natural resource consumption and have direct and indirect impacts on the natural environment (European Commission 2015; Mathur 2013; World Bank 2015). Both directly and indirectly, cities are responsible for 50 to 70 per cent of global greenhouse gas emissions (Satterthwaite 2008). The nature of urbanization will also have consequences on the well-being of residents due to environmental stresses such as pollution. Conversely, well-designed cities will offer benefits to its citizens through availability of green parks and protected areas providing urban ecosystem services (i.e., the benefits to humans provided by nature) like flood mitigation and

green exercise (Elmqvist et al. 2013; Lourdes et al. 2021; Nath, Han and Lechner 2018).

Urbanization, economic growth and environmental impacts are closely linked, with Southeast Asia experiencing consistently high economic growth and a consequent increase in its ecological footprint (Figure 1b) (Mathur 2013). Cities in Southeast Asia are drivers of increased consumption, particularly from the emerging affluent middle class (Douglass and Huang 2007; Liu and Lim 2019; Sheng and Thuzar 2010). There is also a growing disparity between earnings in megacities versus less populous cities (Suzuki 2019). Sustainable development can be a challenge for governments in low- and middle-incomes countries as their focus is on addressing demographic issues, economic growth and basic needs (Krank, Wallbaum and Grêt-Regamey 2010; Krank and Wallbaum 2011) at the cost of their ecological footprints (Evers and Gerke 1997; Karki, Mann and Salehfar 2005; Wiedenhofer et al. 2017). The Global Footprint Network National Footprint and Biocapacity Accounts assessment (2021) shows the growing and unsustainable ecological footprints of Southeast Asian countries, with higher income countries such as Singapore consuming more ecological resources and services in a given year than the earth can regenerate, and other lower income countries following suit (Figure 1b).

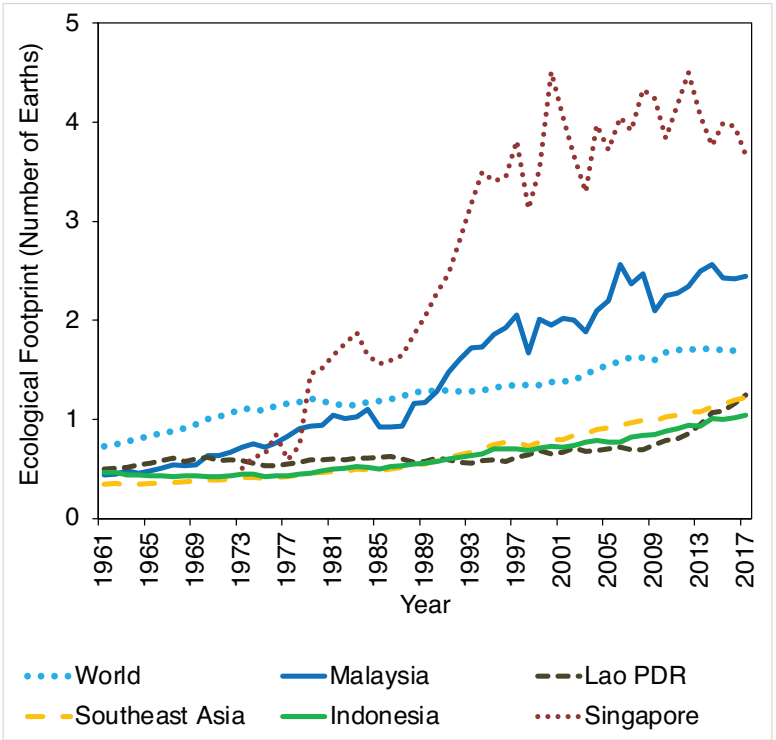
Rapid urbanization in Southeast Asia has come at the expense of the natural environment both directly through the conversion of forests to infrastructure and indirectly through increasing natural resource use and pollution. Asian cities are of particularly high density, and they place a lot of pressure on blue-green infrastructure in terms of clearance for development and also the loss of ecosystem services (Schneider et al. 2015; World Bank 2015). Southeast Asia includes locations with high-density and high-population cities, as well as frontier landscapes such as Borneo, Papua, Sumatra and the central forest spine in Peninsular Malaysia (Figure 2), which are areas of conservation concern (Sloan et al. 2019, 2018; Torre et al. 2019). These frontier regions are also a key focus of infrastructure investment, including foreign direct investment such as the Belt and Road Initiative (Ng et al. 2020; Teo et al. 2019) and national investment, such as Indonesia's new planned green capital in Kalimantan on the island of Borneo (Teo et al. 2020). Cities are generally

Figure 1a: Historical and projected percentages of population residing in urban areas in Asia. Malaysia will be the most urbanized low- and middle-income nation in 2050 while Lao PDR was the least urbanized in 1950 in Southeast Asia.



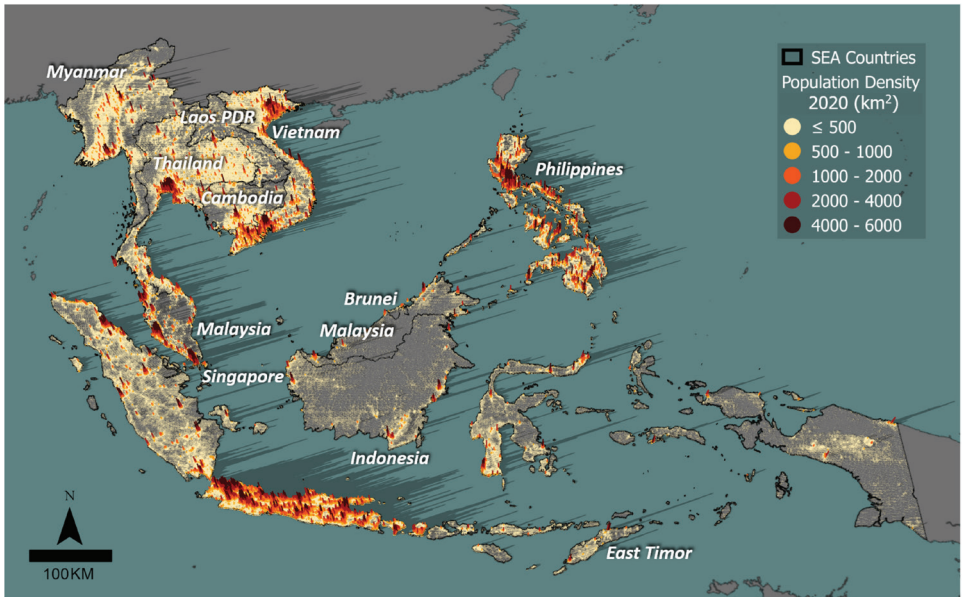
Source: Data from United Nations (2018) World Urbanization Prospects.

Figure 1b: Ecofootprint characterized by the number of earths required if the world's population has a similar lifestyle, quantified by the area of biologically productive land and water required to produce all the resources the countries consume and to absorb the waste it generates, using prevailing technology and resource management practices. An ecological footprint below one earth is considered a sustainable level.



Source: Data from National Footprint and Biocapacity Accounts assessment (2021).

Figure 2: Population density across Southeast Asia varies greatly, with high concentrations in the Philippines, Java and the Mekong Delta as well as around the capital cities of Bangkok and Kuala Lumpur; frontier landscapes exist in Borneo, Papua, Sumatra, and the central forest spine in Peninsula Malaysia.



Source: Data from WorldPop (2020) describing the estimated total number of people in square kilometres.

built in fertile and flat lands suitable for agriculture, areas that tend to be highly productive and which support a unique assemblage of species than commonly found within protected areas; the latter are commonly created in areas that are not suitable for agriculture or infrastructure development and that are often in inaccessible and rugged terrain (Margules and Pressey 2000; O'Neill and Abson 2009).

The direct impacts of urban and infrastructure development in Southeast Asia is of particular concern as the region is a global biodiversity hotspot (cf. Myers et al. 2000) with high biological diversity and home to species not found anywhere else (i.e., endemic species). These ecosystems also provide vital services supporting well-being within cities, through blue-green infrastructure. These services are being lost to further urban expansion and densification for housing and related essential infrastructure development (Lechner et al. 2020a). The overarching challenge for urban sustainability in Southeast Asia, which is particularly important due to the region's unique biodiversity, is to address population growth and urbanization while supporting the environment. This can be accomplished through the application of the Nature-Based Solutions (NBS) concept. NBS uses natural ecosystem processes and functions to provide a range of services such as alleviating flood risk, supplying potable water to urban residents and aiding in climate change adaptation and resilience (Lafortezza et al. 2017; Nesshöver et al. 2017). It is more than mere physical infrastructure; it also allows for a new, more holistic, inclusive and innovative approach to urban planning (Nesshöver et al. 2017; Raymond et al. 2017). Many governments and environmentalists across the world consider NBS to be a necessary to urban sustainability and is considered.

In this paper, we discuss urban biodiversity and NBS in Southeast Asia, paying particular attention to Indonesia and Malaysia—two of the most urbanized countries in the region. Managing urbanization will be one of the most important policy challenges for governments in the region over the next two decades. Governments will have to limit the negative characteristics of urbanization such as adverse environmental impacts, and adapt to and mitigate climate change (Biswas 2016). We first discuss the uniqueness and importance of biodiversity in Southeast Asia, before taking a closer look at urban expansion over the past thirty

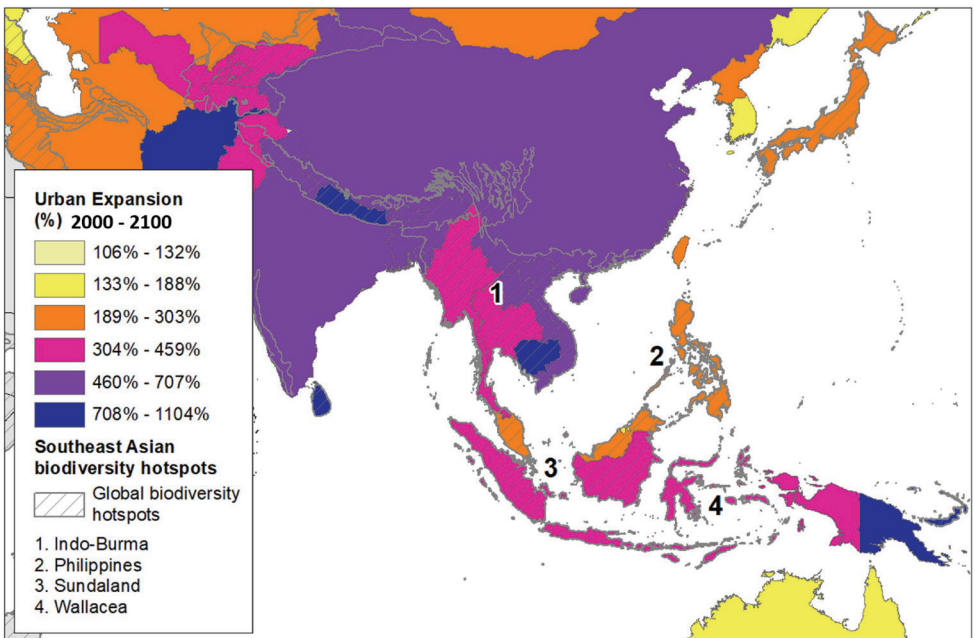
years in Indonesia and Malaysia using a bespoke remote sensing analysis of two cities: Greater Bandung, Indonesia and Greater Kuala Lumpur, Malaysia. Next, we discuss the application of NBS in Bandung and Kuala Lumpur, and Southeast Asia more generally. Finally, we present several recommendations to support blue-green spaces in cities, and key barriers to mainstreaming NBS in Southeast Asia.

2. SOUTHEAST ASIAN BIODIVERSITY

Southeast Asia is one of the most biologically diverse and threatened regions in the world. Although it is home to 20 to 25 per cent of the world's plant and animal species, it makes up only 4 per cent of the earth's surface (Hughes 2017; Sodhi et al. 2010; Woodruff 2010). It is also home to four of thirty-six global biodiversity hotspots which represent locations that have high levels of endemism (i.e., species not found anywhere else) and have suffered significant habitat loss, making them a focal points for conservation efforts (Myers et al. 2000) (Figure 3). Each of these four hotspots have unique geological histories that have contributed to their rich and unique biota which are endemic to each region (de Bruyn et al. 2014; Slik et al. 2015; Sodhi et al. 2004). For example, the Indochina hotspot has 135,000 plant species, of which 52 per cent are endemic, while Sundaland, which includes Malaysia and Indonesia, has 226 amphibian species, of which 79 per cent are endemic (Sodhi et al. 2004). Borneo and Indochina, in particular, are major evolutionary hotspots of fauna and flora; Borneo is considered one of the most diverse and critical biodiversity hotspots in the world (de Bruyn et al. 2014). Aside from Africa, Southeast Asia is recognized worldwide for having the greatest diversity of extant (and charismatic) megafauna, these include the Asian elephant (*Elephas maximus*) and tigers (*Panthera tigris*) (Jambari et al. 2019; Magintan et al. 2017; Ripple et al. 2016).

Southeast Asia has an important role in global biodiversity conservation and in the provision of ecosystem services especially carbon sequestration and storage (Sullivan et al. 2017); yet it is also under significant pressure from urban land expansion (Figure 3) and deforestation (Estoque et al. 2019; Hughes 2017; Wilcove et al. 2013).

Figure 3: Projected urban land expansion in Southeast Asia and surrounding countries



Note: Southeast Asia includes 4 of 36 global biodiversity hotspots.

Source: Spatial data from Gao and O'Neill, (2020) overlaid with global biodiversity hotspots (Myers et al. 2000); Spatial data from Mittermeier et al. (2004)).

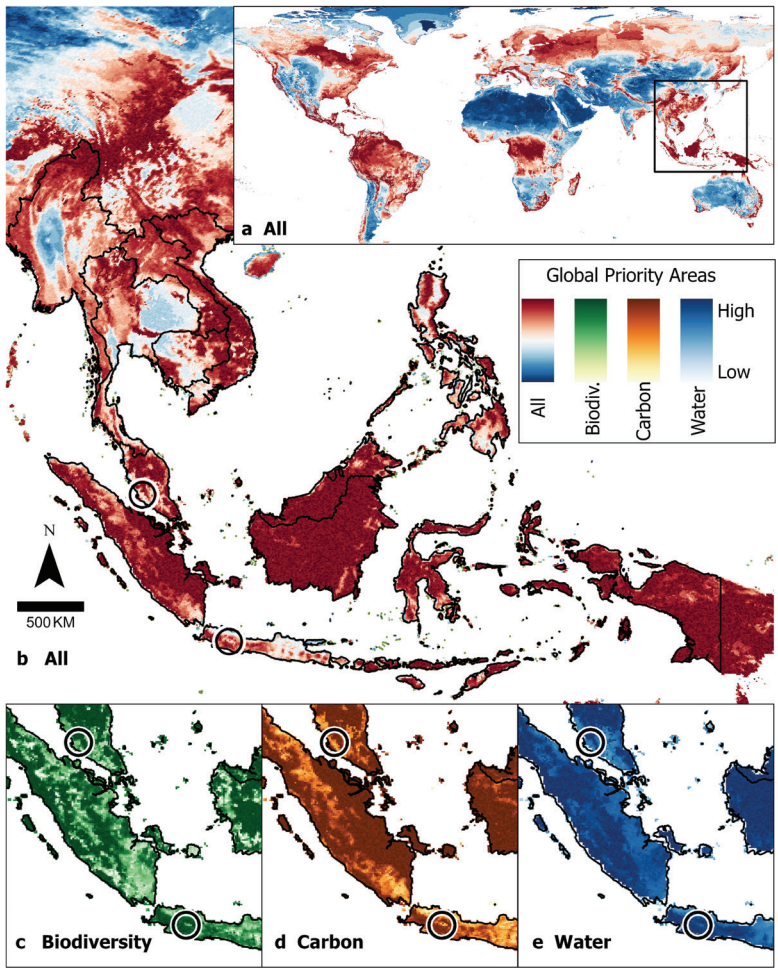
Jung et al.'s (2021) assessment of global priority areas for carbon, biodiversity and water shows that the region is particularly critical in all three aspects, with Indonesia and Malaysia having extensive high priority areas (Figure 4).

Biodiversity in Southeast Asia is not just confined to its contiguous forests but is also found in its cities. While there are a limited number of studies in Southeast Asia on urban biodiversity (i.e., except for Singapore), field-based studies of Greater Kuala Lumpur have shown that urban forests and ponds have the capacity to support biodiversity even though they are surrounded by a high density urban matrix (Aida et al. 2016; Samantha et al. 2020; Tee et al. 2019a; Teo et al. 2021). Biodiversity in urban environments include common and ubiquitous species, from macaques to more cryptic species such as pangolins (Samantha et al. 2020; Tee et al. 2019a). Remanent green patches and surrounding habitat can be surprisingly biodiverse and provide habitat for important IUCN red-listed species ranging from the large and endangered Malay tapir (*Tapirus indicus*) to the lesser mouse deer (*Javan Chevrotain*) whose conservation status is unknown due to the lack of knowledge about the species (Figure 5). In contrast, cities in high-income countries, including Singapore, which have a long history of urbanization, are relatively poor in biodiversity and are actively undertaking rewilding or conservation programmes (Centre for Liveable Cities and National Parks Board 2015; Harris 2021).

3. ASSESSMENT OF URBAN GREEN SPACE LOSS IN GREATER BANDUNG, INDONESIA AND GREATER KUALA LUMPUR MALAYSIA

In the following section we take a closer look at the nature of urban expansion in Indonesia and Malaysia using remote sensing, focusing on two cities: Greater Bandung, Indonesia and Greater Kuala Lumpur, Malaysia. Greater Bandung, or the Bandung Basin, consists of Bandung Regency, West Bandung Regency, Cimahi City, Bandung City and five districts from Sumedang Regency; a total of 8.2 million residents

Figure 4: Global priority areas for terrestrial biodiversity, carbon and water combined (a) globally, and (b) Southeast Asia. Individual maps of (c) terrestrial biodiversity, (d) carbon and (e) water for Peninsular Malaysia and West Java with the location of Kuala Lumpur and Jakarta highlighted.



Source: Spatial data from Jung et al. (2021).

Figure 5: Examples of species observed via field-based camera traps within and in the vicinity of urban areas in Malaysia. Their respective IUCN Red List Category describing their extinction risk (02/09/2021) (IUCN 2021a) are as follows: (a) leopard cat (Prionailurus bengalensis)—Least Concern; (b) sun bear (Helarctos malayanus)—Vulnerable; (c) Malay tapir (Tapirus indicus)—Endangered; (d) wild boar (Sus scrofa)—Least Concern; (e) Melanistic leopard (Panthera pardus)—Vulnerable; and (f) lesser mouse deer (Javan Chevrotain)—data deficient and therefore inadequate information available to assess extinction risk.

Source: Photo credits Badrul Azhar.

in 2014, it is one of the five largest cities in Indonesia (Tarigan et al. 2016). Surrounded by mountains and 2,400 m-high volcanic terrain, the seismically active region with its tropical monsoon climate is highly susceptible to natural hazards such as floods, earthquakes and landslides (Gumilar et al. 2015; OECD 2018). Greater Kuala Lumpur is the metropolitan area of Kuala Lumpur, the capital of Malaysia. Greater Kuala Lumpur comprises five districts in the state of Selangor (Petaling, Gombak, Klang, Hulu Langat and Sepang) and the federal territories of Kuala Lumpur and Putrajaya. Greater Kuala Lumpur extends to Rawang in the northwest, Semenyih in the southeast and Port Klang in the southwest, with Kuala Lumpur at its centre. Development is constrained towards the east by the relatively intact and elevated forests in the Titiwangsa range and towards the west by the coastline forming the Straits of Malacca.

3.1 Remote Sensing Methods

A remote sensing timeseries analysis (Ang et al. 2021; Lechner et al. 2019) was undertaken to determine the distribution and spatio-temporal changes of urban green spaces and built infrastructure in both locations. We used Google Earth Engine (GEE), a publicly accessible, cloud-based platform that provides access to high-performance computing capacity and hosts a growing collection of remote sensing data (Gorelick et al. 2017; Mutanga and Kumar 2019; Pericak et al. 2018). Landsat 5 and 8 satellite data were utilized as they provide the most comprehensive historical data for our study areas. Remote sensing can be challenging in the tropics due to cloud cover; a number of pre-processing steps were therefore undertaken to address the problem. Firstly, after filtering for the least cloudy years, four timesteps were selected at both locations over a thirty-year period from 1989 to 2019 for Greater Bandung and a thirty-one-year period from 1988 to 2019 for Greater Kuala Lumpur. For each of the years a multidate image composite was created using a cloud mask, and the median pixel value was then calculated (Ang et al. 2021; Lechner et al. 2019). Two spectral indices, the normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) were then calculated from a range of Landsat bands and used as threshold in order

to map vegetation greenness, urban areas and waterbodies using the following equations:

NDVI = (Near Infrared – Red)/Near Infrared +Red)
NDWI = (Green – Near Infrared)/(Green + Near Infrared)

NDVI is often used to monitor and differentiate vegetation from other land cover to identify the health, density and greenness of vegetation (Shaharum et al. 2020). NDWI, in turn, is a good indicator for mapping surface waterbodies, drought conditions and crop water content. Both indexes have values which range from –1 to +1 which were divided into the various land covers using thresholds to classify the key land cover classes. The NDVI classification threshold used in this study was –1 to 0 for water body, 0 to 0.5 for built-up area and greater than 0.5 to 1 for sparse to dense vegetation. Additionally, any pixels with NDWI threshold values greater than –0.1 were converted to water body land cover class to improve classification accuracy.

3.2 Thirty Years of Land Cover Change

The remote sensing analysis of Greater Kuala Lumpur showed a dramatic reduction in urban green spaces in and around the metropolitan area (Figure 6). The area mapped as urban increased by nearly three times, from 461 km^2 to 1,123 km^2, over the thirty years. Urban sprawl has grown in all directions from the central federal territory of Kuala Lumpur. However, it is restricted by the mountain ranges in the east. Even though the urban footprint has expanded significantly, large remnant patches of urban green spaces remain within Greater Kuala Lumpur in 2019.

The remote sensing analysis of Greater Bandung (Figure 7) showed large changes in vegetation cover and decreases in greenness within and around the city, associated with land conversion from forests and rapid urbanization (Agaton, Setiawan and Effendi, 2016). In the past thirty years, the total area mapped as urban more than doubled, from 368 km^2 to 830 km^2, with urbanization generally occurring in the valley floors, constrained by topography. In contrast to Greater Kuala Lumpur, it appears that there are few large areas of urban forest within Bandung

Figure 6: Timeseries of Greater Kuala Lumpur, Malaysia from 1988 to 2019 showing the patterns of urban expansion

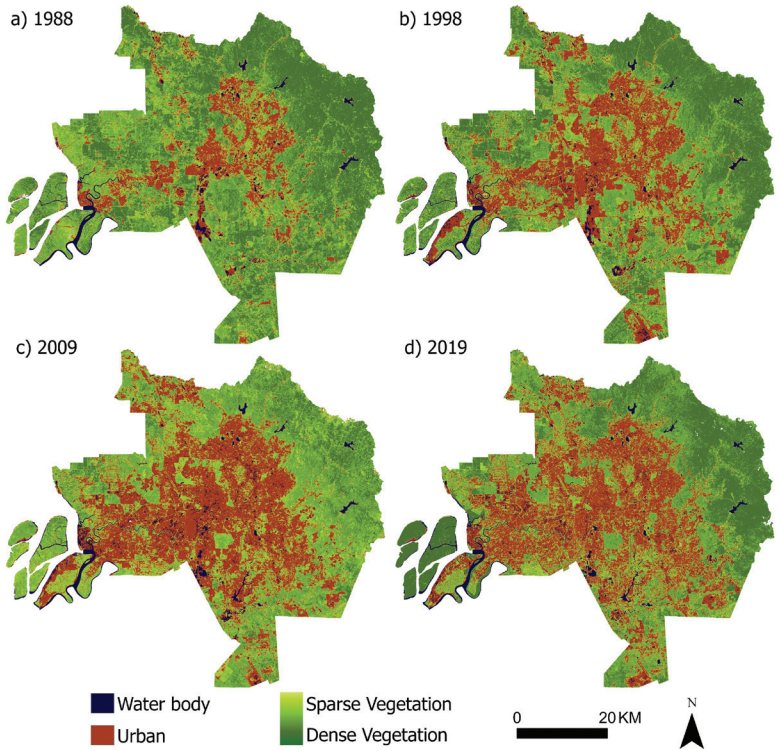
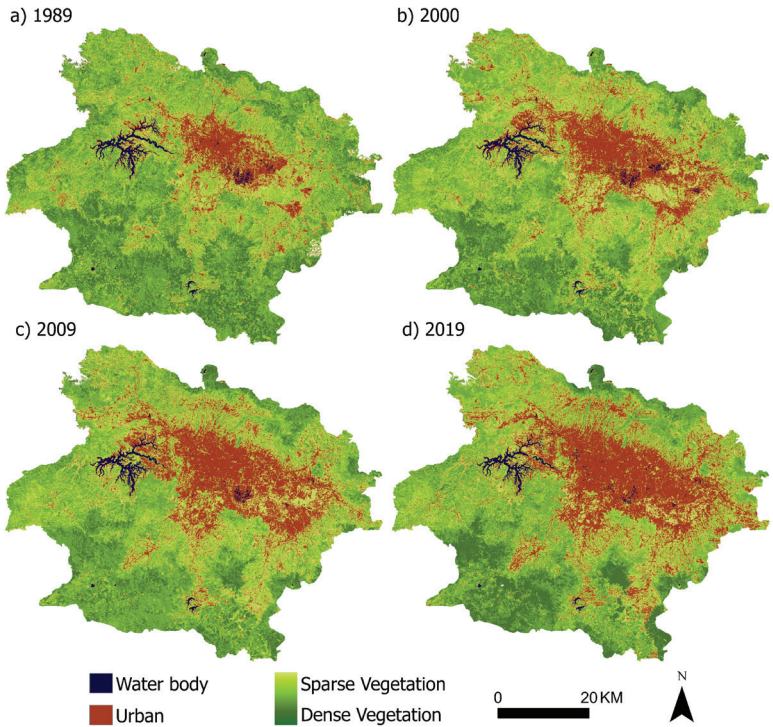


Figure 7: Timeseries of Greater Bandung, Indonesia, from 1989 to 2019 showing the patterns of urban expansion.



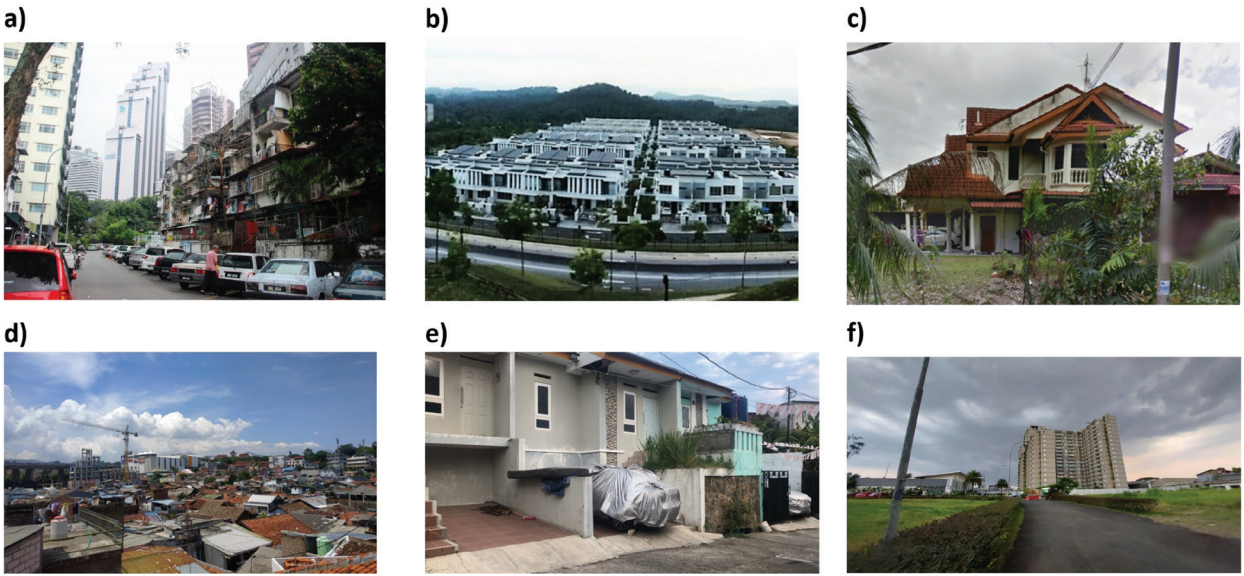
city itself, especially in areas upstream from Bandung. Consequently, the decrease in infiltration area increases the possibility of flooding in downstream areas of Bandung which is a major concern for planners (Prihatini et al. 2018).

On the peripheries in the peri-urban areas of Greater Kuala Lumpur and Bandung, new housing stock is generally of lower density, with Greater Kuala Lumpur having greater vertical density in both the inner city and peripheries (Figure 8). In Greater Kuala Lumpur, new housing stock can be in the form of greenfield development including master-planned gated communities converted from either secondary vegetation regrowth or agricultural lands such as oil palm or rubber plantations. These master-planned developments are frequently sold as "eco" housing, or "green" communities because of the emphasis placed on the provision of communal green spaces (however small) within the estate. While in the peri-urban areas of Bandung, greenfield development on the peripheries tend to be single storeyed, with housing footprint taking up the majority of the property boundary and with fewer green spaces due to the high-density of development (Budiyantini and Pratiwi 2016). The original land use for these greenfield developments in Bandung tended to be rice paddy fields. In both regions, the share of housing development, accounted for by more expensive master-planned development of gated communities with larger building footprints is growing to cater to the emerging middle-class (i.e. Figure 8b).

4. NATURE-BASED SOLUTIONS AND APPLICATIONS IN BANDUNG AND KUALA LUMPUR

NBS include connected green (i.e., vegetation), blue (i.e., water) and hybrid (grey-green) infrastructure in cities which provide environmental, social, cultural and economic benefits. An NBS approach can potentially underpin the urban design and planning strategies in Bandung and Greater Kuala Lumpur, as well as other cities in Southeast Asia, addressing a range of environmental issues critical for the tropics. Examples of NBS include protection, construction and restoration of wetlands, permeable pavements, protection or restoration of riparian areas in river channels,

Figure 8: Examples of urban settlements in Greater Kuala Lumpur include: (a) high-density apartments, (b) new suburban "eco-village", and (c) traditional Malaysian villa housing. Examples of the range of urban settlements in Greater Bandung include: (d) high-density settlement, (e) peri-urban settlement, and (f) high density apartments



Source: Photo credits Alex Lechner for (a) to (c); photo credits Saut Sagala for (d) to (f).

floodable parks and retention ponds, green roofs and walls, street trees and green parks. These NBS range from highly engineered hybrid infrastructure such as green walls to the protection of existing natural and semi-natural ecosystems. NBS also considers biodiversity and ecosystem functions, as well as the utilization of native endemic species, to be integral to the approach (Eggermont et al. 2015).

More formally, NBS is defined by the European Commission (2021) as:

> Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.

IUCN (2021b) defines NBS as follows:

> Nature-based Solutions are actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits. They are underpinned by benefits that flow from healthy ecosystems and target major challenges like climate change, disaster risk reduction, food and water security, health and are critical to economic development.

While this concept has been more extensively applied in Europe (Eggermont et al. 2015; Faivre et al. 2017; Raymond et al. 2017), there is arguably a much greater need for it in Southeast Asia due to the rapid pace of development, loss of green space and biodiversity and the pressing need to mitigate and adapt to climate change (Lechner et al. 2020a). While there are a number of demonstration projects across Southeast Asia such as urban forest and wetlands habitat restoration and protection to regulate water in the Mekong River in Laos (Sales 2019) and water-sensitive urban design projects in Vietnam (Asian Development Bank 2019). One reason for a lack of application of NBS in Southeast Asia

may be the very different constraints in terms of the knowledge and capacity. Additional challenges include the scale of urbanization, region-specific biophysical, environmental and climatic context, complexity of restoration, human-nature relationships and conflicts, and policy and governance context (Lechner et al. 2020a). Approaches that are similar to NBS have been used for decades in Southeast Asia (Dang et al. 2021; Lourdes et al. 2021), but these have a narrow focus, demonstrating ecosystem-based adaptation approaches (i.e., Payment for Ecosystem Services), commonly for a single service, rather than addressing the whole suite of cross-sectoral impacts (e.g., links between multiple ecosystem services, biodiversity, governance, society and the economy) advocated by an NBS approach (Cohen-Shacham et al. 2016; Raghav et al. 2020; Raymond et al. 2017).

A key benefit the application of NBS can bring to Southeast Asia is in the form of climate change adaptation; the region is projected to be disproportionately impacted by climate change, with Myanmar, the Philippines, Vietnam and Thailand being among the top ten countries to be most affected by extreme weather events globally (Eckstein et al. 2020). Creating climate resilient systems which can prevent, withstand, respond to, and recover from a disruption is especially important for addressing hydrometeorological hazards, such as those associated with increases in heat stress in cities that already have hot and humid baseline climates (Matthews et al. 2017; Mora et al. 2017), and increased riverine and coastal flooding due to more intense monsoons and sea-level rise (Hallegatte et al. 2013). NBS also has an important role upstream in regulating urban water catchments. There are a number of cases where the securing and regulating of water supplies in catchment headwaters have been done through the protection and restoration of natural forests; for example, in flood regulation and sediment retention in Myanmar (Mandle et al. 2017) and in Malaysia where payment for ecosystem services is being proposed to protect the Ulu Muda catchment area, alongside nature-based tourism and biodiversity (Yayasan Hasanah 2018).

In Greater Kuala Lumpur and Bandung, one of the most important applications of NBS is for the mitigation of floods associated with high and intense rainfall events, and impervious urban land cover (Chan 2012; Khailani and Perera 2013). In Malaysia 9 per cent (29,000 sq. km) of its

land area and 22 per cent of the population (4.82 million) are impacted by flooding, costing an average of RM915 million (~168 million GBP) annually (Raman et al. 2015). Indonesia, meanwhile, is ranked 12 out of 35 countries at risk of multiple hydrometeorological hazards, including flooding (Stanton-Geddes and Vun 2019).

Future applications of NBS in both cities can build on existing programmes, which tend to have a narrow focus on flood mitigation, one of the main hydrometeorological hazards. In Bandung, grey-green measures applied include construction of retention ponds, rain barrels and biopores, and the most recent and well-known project, the Gedebage wetlands (Hidayat, Herwindo and Bachri 2019). More broadly, the Citarum Watershed Action Plan and citizen initiatives such as the Tunas Nusa Foundation have raised awareness of NBS. While, Greater Kuala Lumpur has also undertaken a number of programmes to address flooding; perhaps the most well-known and forward thinking is the Putrajaya wetlands, built as part of Malaysia's planned capital in 1995. Putrajaya was designed as a green city with the PutraJaya wetland complex at its heart (Moser 2010). The Putrajaya Lake and wetlands is over 600 hectares in area; constructed to create a balanced biogenic environment and to support the eco-hydrological management of the catchment, including water purification and flood mitigation (Majizat et al. 2016). Across the region, lessons learned from existing programmes such as described above need to be reconsidered through an NBS lens to accelerate its uptake in Southeast Asia.

5. WAY FORWARD

5.1 Prioritize Blue-Green Infrastructure

Across Southeast Asia, particularly in rapidly urbanizing cities such as Greater Bandung and Greater Kuala Lumpur, blue-green spaces are encroached upon, degraded and/or fragmented. There is an increasing urgency to implement an NBS approach for both the local and global benefits it provides, especially in preparation for climate change. Unlike European cities, where NBS often needs to be retrofitted to existing infrastructure, there is an opportunity to utilize and protect

existing natural areas within the urban matrix, as part of precinct-level urban design and city-wide planning. Alternatively, Southeast Asia brownfields include heavily degraded urban environments at scales not seen before (Lechner et al. 2020a), and can be very challenging and costly to restore and rehabilitate (Coleman, Miller and Mink 2011; Fernandes and Guiomar 2018; Pavao-Zuckerman 2008). There is a need to prioritize the last remaining green spaces in the urban matrix, conserve high-value blue-green spaces in terms of ecosystem service provision (including biodiversity), and ensure greenfield development is planned using appropriate spatial planning approaches (Lourdes et al. 2021). Importantly, NBS development needs to apply a mitigation hierarchy (i.e., avoidance, minimization, rehabilitation, offsetting and compensation) which focuses on protecting existing biodiversity and averting biodiversity loss in the first place rather than replacing nature with engineered types of NBS (i.e., hybrid infrastructure).

Southeast Asian cities provide a unique opportunity for realizing urban development where both nature and residents co-exist. Such green urban approaches have already been applied in the region, such as for Indonesia's new planned capital in Borneo (Teo et al. 2020), Forest City in Johor, Malaysia (Rahman 2017) and DBKL's vision to become a Tropical Garden City (Nor Akmar et al. 2011). However, such approaches (not only in Southeast Asia), commonly focus on developing urban green spaces which are aesthetically pleasing, but may not support ecological processes and functions using evidenced-based approaches advocated by NBS. This limits the ecological benefits. For example, Rahman (2017) evaluated Forest City and found that it "leans more towards green marketing than environmental substance". Meanwhile, Teo (2020) identified major concerns around spillover impacts on the environment, which may potentially result from siting Indonesia's new capital in Borneo, one of the most important biodiversity and carbon hotspots in the world.

The case of Singapore can be instructive with regard to the potential for developing green cities with sustainable and biodiverse ecosystems. The city-state has a history of extreme degradation of its ecosystems due to rapid development—more than 90 per cent of its original forest cover is lost—followed by ambitious conservation strategies that maintain or

restore biodiversity. The city is now covered with more than 50 per cent vegetation and is home to 40,000 non-microbial species. Evidence-based approaches including monitoring performance using healthy biodiversity indicators, can be traced to several strategies spearheaded by the National Parks Board since 1990. These involve intensive planning, monitoring, and investment in science, with the city benefiting from a long history of ecological research (Tan and Abdul Hamid 2014), especially relative to its neighbours (Lourdes et al. 2021). Such ecological knowledge informed conservation plans involving remaining native habitats and (dominant) managed ecosystems, as exemplified in the National Biodiversity Strategy and Action Plan, the Nature Conservation plan (National Parks Board 2019), and more recently the City in Nature initiative, which is part of the Singapore Green Plan (National Parks Board 2021). Progress in biodiversity science and management can also benefit the region more generally, as illustrated by the Singapore Index on Cities' biodiversity, also known as the City Biodiversity Index; which is a self-assessment tool for monitoring the progress of biodiversity conservation efforts against a city's own baseline. The tool is promoted by the Convention on Biological Diversity to encourage cities to support biodiversity and ecosystem-based management (Centre for Liveable Cities and National Parks Board 2015).

5.2 Living with Nature in Southeast Asia

As the world becomes more and more urbanized, people increasingly have less direct contact with nature. Not only do residents lose the benefits that come from interactions with nature, in the long term there is concern that the extinction of nature experiences would reduce motivations for sustainability and conservation (Cox et al. 2017; Gaston and Soga 2020). The less we interact with nature, the less we care about nature and are willing to engage with global environmental issues such as climate change and biodiversity loss. Conversely, in cities such as Greater Kuala Lumpur and Greater Bandung, the remaining green spaces are increasingly forested remnants in locations that are too difficult to develop because of their topography and—at least in the case of Kuala Lumpur—are home to high biodiversity. Therefore, either through restoration of

forested remnants or development encroaching on habitat, wildlife may increasingly come in closer contact with humans. Furthermore, wildlife from surrounding natural areas may colonize urban areas as these are free from predators and can provide abundant food and shelter (Soorae 2018). These close encounters can give rise to human cohabitation problems (Sodhi et al. 2004; Tee et al. 2019b) and human-wildlife conflict due to the perception—and at times real risk—that wildlife is dangerous or carry diseases (Mackenstedt, Jenkins and Romig 2015). Compared to European cities experiencing high rates of urbanization, which have relatively less "dangerous" wildlife, the human-nature relationship and potential for conflict in Asian cities are quite distinct by comparison.

Hence, an NBS approach needs to be tailored to suit Southeast Asia to address some of its unique challenges (see Lechner et al. 2020a) by incorporating an understanding of local needs and perceptions and the characteristics of its tropical ecosystems and wildlife. For example, the construction of retention ponds to mitigate flooding is a widely advocated type of NBS in temperate regions, however, in tropical cities this can create new habitats for mosquitos which in turn may become malarial hotspots (Swift et al. 2019; Zellweger et al. 2017). In addition, there is a need to pay attention to local attitudes, perceptions of nature, and the willingness to pay for ecosystem services (Nath et al. 2018; Norhuzailin and Norsidah 2015; Paul et al. 2020). Heterogeneity in these attitudes and perceptions also need to be recognized as there can be a great variation in preferences relating to development and conservation even within the same community (Lechner et al. 2020b). Conditions are also likely to evolve as residents' relationships with nature and acceptance of naturalness change in response to NBS policies and the rollout, familiarity, and hopefully the success of NBS projects (Lechner et al. 2020a; Pavao-Zuckerman 2008).

5.3 Recommendations

NBS and similar approaches such as ecosystem-based adaptation in Southeast Asia are still the exception rather than the rule. There is a pressing need to build momentum. While the importance of NBS is recognized globally in policies and by multilateral organizations (Seddon

et al. 2020), as evidenced in the Climate Change and Land Report of the Intergovernmental Panel on Climate Change (IPCC), Convention on biodiversity (PEDRR and FEBA 2020), and the IUCN (IUCN 2017), there are still many unknowns in Southeast Asia where such approaches have only recently been applied in policy and planning. If NBS is to be mainstreamed in the region, there are a range of issues that need to be addressed (Frantzeskaki et al. 2019; Lechner et al. 2020a; Raghav et al. 2020; WEF 2020):

1. Knowledge gap and awareness: more guidance and demonstration projects supporting the design of NBS, particularly in the tropics is required. Greater understanding of how highly biodiverse and heterogeneous tropical urban ecosystems with high endemism can support a range of NBS is needed. NBS design needs to be supported by the best physical and social science.
2. Evidence-base for benefits and disservices: there are still many unknowns, such as limited metrics and indicators for measuring success (e.g., comparing alternative NBS or NBS versus grey infrastructure) and there is a need to demonstrate the substantial benefits from NBS for the full breadth of co-benefits, especially in comparison to grey solutions. The metrics developed need to support an assessment of short-term vs. long-term benefits based on a range of values (including monetary value and social) and equity between beneficiaries. Such approaches need to integrate different forms of knowledge such as big data, scientific theory, socio-demographic information, and practice-based technical knowledge.
3. Support from institutions and stakeholders: NBS requires cross-sector and institution-level support both at the implementation stage and for developing policy. Collaboration is needed between different layers of government and public and private sectors which requires co-production through partnerships between business, academic, professional, policy and civil society stakeholders. Most importantly, NBS need to be designed to improve local livelihoods and well-being and address environmental justice to ensure community support.
4. Finance: Mechanisms for leveraging finance is required to create the incentives for investment (i.e., corporate social responsibility

commitments and voluntary and compliance market opportunities such as carbon credits), especially when the benefits are yet to be fully articulated. This will require innovative financial mechanisms to be developed and supported by cities to pursue green economic development. The private sector needs to support policy development to ensure long-term sustainability, identify opportunities for scaling up, and set consistent price signals.

Mainstreaming NBS in Malaysia and Indonesia, and across Southeast Asia more broadly, will be a significant challenge. North-South collaboration might be an important part of a strategy, such as building off the massive efforts applied by the European Commission to mainstream NBS, i.e., NBS is central to the EU urban agenda and the EU climate adaptation strategy. Replicating such approaches via a regional body such as ASEAN, though idealistic, also has potential, with ASEAN currently in the process of raising awareness of the opportunities for implementing NBS for climate resilience, which include mainstreaming NBS into national planning across ASEAN countries (Environment Division of the ASEAN Secretariat 2020). Collaboration and learning, particularly South-South collaboration supported by ASEAN, drawing on successful projects and applications in the region, and knowledge on the application of co-benefits which are more advanced such as in the context of flood and water quality management applications, need to be a key part of the strategy (Hamel and Tan 2021). However, a lack of political will and strong governance, especially when it comes to implementation and enforcement, and an overarching desire to pursue economic growth in the fastest and easiest (and often cheapest) way need to be overcome for an NBS approach to be successful in Southeast Asia.

Cities need to develop along climate-resilient pathways which combine adaptation and mitigation while achieving sustainable development (Denton et al. 2015). Southeast Asian cities are particularly vulnerable to climate change, but also have the potential to lead climate change action in the region. In the Global North, there are numerous examples where cities are taking action on climate change, and committing to carbon-neutral targets, even though their national governments have failed to act. Megacities in Southeast Asia have populations, economies and

ecological footprints which rival small countries and therefore can take on leadership roles. Finally, while the COVID-19 pandemic has impacted many countries' and cities' economies, in particular Indonesia (which was recently downgraded to a lower-middle income country (World Bank 2021)), many jurisdictions around the world have proposed strategies for green infrastructure-led economic recoveries. Such strategies could be replicated in Southeast Asia using NBS as a guiding principle.

6. CONCLUSION

Southeast Asia needs a vision for adapting to and mitigating climate change and biodiversity conservation where NBS is central. The latest IPCC report made it clear that the world is at a turning point, and that it is in this decade where changes need to be made. The UN secretary general describes this decade as a "code red" for the earth. Cities are at the heart of our planetary crises, as they are the driver of global ecological and environmental impacts, the main recipient of those impacts, and where many of the solutions need to be found. Globally, Southeast Asia has a unique role, as it is home to some of the most important ecosystems, global hotspots for biodiversity and carbon storage, and responsible for an increasingly larger share of rising greenhouse gas emissions with an increasing ecological footprint. Given the urgency of our global challenges, transformational change is needed in Southeast Asia, fundamentally changing urban ecological, technical, economic, and social systems while still supporting sustainable development. Otherwise poorly planned infrastructure has the potential to lock in negative environmental and social impacts for decades to come.

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