Special Ecology Feature

Biodiversity's Crucial Role in the Modern Singapore City

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Photography as credited

Introduction

The purpose of this article is to review the relationship between cities and their biodiversity, with special reference to Singapore, and to set the context for the succeeding articles on the management of particular groups of plants and animals in Singapore. Biodiversity and greenery play crucial roles in providing ecosystem services, improving human health and wellbeing, and securing the quality of life for city dwellers. It is axiomatic that cities do contain biodiversity; the questions are how much and how important biodiversity is to the daily and long-term lives of the residents.

The term "biodiversity" is short for "biological diversity". It describes the variety and diversity of all life on land, in freshwater, and in the sea, including the places or ecosystems where they live and the genes they contain. However when we talk about biodiversity, we usually think of the individual birds, plants, fish, insects, and other species found in an area. Singapore is unusual in being a city state, where the national boundaries equal the city boundaries, in being equatorial, and in having substantial marine as well as terrestrial biodiversity.

Ecosystem diversity

Ecosystems are formed through the interaction of living plants and animals with the non-living world of decaying matter, soils, rock, and water. These interactions form a complex web, in which each animal and plant—both the species and the individuals—affects and is affected by others. It is the diversity at both the species and individual levels that creates the higher level ecosystem diversity in which they reside. Furthermore, there are many different ecosystems that can be recognised at increasingly fine levels. There are forest, freshwater, and marine ecosystems. Different forests may represent the forest ecosystem on dry land, on steep slopes, in areas that are seasonally or permanently flooded, or with fresh or brackish water, and forests that in different parts of the world might shed their leaves annually or remain evergreen. Each can be recognised as an ecosystem with a different and unique set of plant and animal species, relying on a unique set of physical and chemical conditions.

Species diversity

In very extreme or harsh conditions, there tends to be only a few, highly resilient species of plants or animals. But most ecosystems contain hundreds to thousands of species, especially when very small invertebrates and micro-organisms are included, and especially in tropical situations such as Singapore. The species that occur in a particular ecosystem can be predicted fairly accurately, in different parts of the world, yet there are still many insects, fungi, bacteria, quite a lot of plants, and even big animals not yet named by scientists. Singapore is thought to possess (or have possessed) around 40,000 species altogether, of which some 500 are vertebrates (mammals, birds, reptiles, amphibians, and freshwater fishes) and about 2,050 species are native plants.

Genetic diversity

Genetic diversity exists within populations, between populations within a species, and between species. This variation is the basis for huge economic advances in agriculture, the domestication of crops and animals, and food production around the world.

ABOVE Singapore's mangrove forests contain several specimens of the very rare tree *Bruguiera hainesii*. It is estimated that only 200 individual trees of *B. hainesii* can be found in the wild, making it one of the most endangered mangrove tree species in the world (Photo: Yang Shufen).

The Need For Biodiversity Conservation

Over the past few decades, the importance of biodiversity for all human activities has been appreciated more and more. From an initial concern over the reduction or disappearance of charismatic big animals, such as the blue whale and giant panda, the emphasis has shifted to an understanding of fully functioning ecosystems and the services they provide. These services are essential to human survival. The disappearance of a single species is sad and poses ethical issues, but a crop failure can kill.

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Biodiversity sustains all life. All foods, with very minor exceptions, are derived from plants or animals. The majority of medicines are either derived from organisms or have been developed as a result of related discoveries in organisms. Soils would not form and nutrients would not be transferred from the soil to our foods, were it not for micro-organisms. Many crops would not be pollinated and seeds and fruits would not form, were it not for bees, moths, butterflies, and other pollinating insects.

These processes often occur in places remote from cities and people might never see them happening, but they are essential to people within the cities. Singapore imports food from around the world, where ecosystems are changing, forest is being removed, water quality is being altered, and soil formation is changing, and Singaporeans are directly causing some of these changes by their purchases.

Within the cities too, biodiversity is saving us money and generating incomes. Most Singaporeans benefit from recreation opportunities in parks and nature reserves. They walk in the shade of roadside trees that have been selected for their ability to grow in limiting conditions. Singapore's universities and polytechnics make use of terrestrial and marine species to carry out research and to train future generations of scientists. Every year, more than 100,000 school pupils are required to visit the nature reserves as part of their formal educations and others do so for relaxation and enjoyment.

Human health is greatly affected by our surroundings. Greenery in the city reduces stress and provides cooler temperatures, space for exercise, and places to chill out. It has even been shown that recuperating hospital patients recover faster when provided with views of nature and greenery, and there is no reason to think that Singaporeans are different from other people in this respect.

In other words, the loss of one species is tragic, but not a disaster for the survival of humans. But when many species are being threatened and disappearing, it is a symptom of something going wrong, and we had better do something about it.

ABOVE The KTM Railway Line has great potential to be a green corridor (Photo: Wong Tuan Wah).

Role of Cities in Biodiversity Conservation

Cities are administrative units that also include green spaces and agricultural as well as natural areas. There is no internationally recognised definition for the terms "urban" and "city". Most countries create their own categories based on administrative data (105 countries), population density (100 countries), economic characteristics (25 countries), and the availability of infrastructure (18 countries). Twenty-five countries provide no definition to describe "urban", while six countries, including Singapore, classify their entire populations or entire landscapes as urban (UN Habitat Report 2006/7).

"Urban biodiversity" can therefore be defined as the variability among all living organisms from all sources and ecosystems within an area with an increased density of human-created structures in comparison to the areas surrounding it. The importance of urban biodiversity was recognised during the United Nations Convention on Biological Diversity of 1992.

Cities have an important role to play in the conservation of biodiversity because:

- More than half of all the people in the world live in cities.
- Biodiversity within the city may be the only form of plants and animals the residents ever notice, even if it is just potted plants and garden birds.
- Greenery is important for the health and wellbeing, recreation, and de-stressing of people living in cities. Natural greenery is thought to be more effective than artificial greenery in providing such benefits.
- As administrative centres, cities often determine the budgets, policies, and practices of much wider areas, including the management of their biodiversity.
- Cities contain the manpower, expertise, and institutions that can influence the future of biodiversity, such as museums, botanical gardens and zoos, research institutes, and planning agencies.
- Cities draw resources (food, water, recreational space, ecosystem services) from a wide catchment area or hinterland of countryside around them.
- Cities are totally dependent on sources of biodiversity somewhere, even if they are remote from the cities themselves and invisible to the residents. This might sound radically extremist but it is not wrong.

Key Ecosystems and Biodiversity of Singapore

Lowland evergreen rain forest

This was the dominant natural vegetation type of Singapore prior to disturbance by man. It has very high species diversity of all groups of plants and animals, and is dominated by canopy trees of the family *Dipterocarpaceae*. It is estimated that lowland evergreen rainforest once covered 80 percent of Singapore (Corlett 1991), but by the 1870s, scarcely 50 years after the arrival of Raffles to these shores, more than 90 percent of the rainforests had been cut. What remained was found mainly on hilltops and in small groves (Wallace 1869). Today, roughly 250 hectares (or 2.5 square kilometres) of primary lowland rainforest remain (Corlett 1997), less than 0.5 percent of the original habitat. This is embedded within a much larger matrix of secondary forest.

Primary forests harbour not only high plant diversity but also the richest associated animal life. A small study plot in the Bukit Timah Nature Reserve supports over 300 tree species, while the Central Catchment Nature Reserve has even higher plant diversity and a concomitant wealth of animal life. In addition, primary forests support the greatest biomass, highest productivity, and in general provide unparalleled ecosystem services compared to less diverse terrestrial habitats.

Freshwater swamp forest

One of the most threatened natural habitats in Singapore and Malaysia is the freshwater swamp forest. This is a distinct forest type restricted to flood-prone areas and found only in a very limited area of Singapore, near Upper Seletar Reservoir (Ng and Lim 1992). Once also found in Jurong and the Mandai area (Corner 1978), this forest is characterised by plants adapted to wet, marshy conditions bearing interesting features, in particular stilt roots and breathing roots (not unlike those found in some mangrove species). Many of the species that Corner listed as occurring in Nee Soon are species that are associated with swampy areas such as Asam Paya (*Eleiodoxa conferta*), Meranti Paya (*Shorea platycarpa*), Marsh Pulai (*Alstonia spathulata*), and Terentang (*Campnosperma squamata*), while others can be found in a typical lowland forest (*Gluta wallichii*, *Knema intermedia*, *Blumeodendron tokbrai*, *Santiria apiculata*, *Bhesa paniculata*, *Koompassia malaccensis*). This is a key ecosystem for Singapore's endemic freshwater crabs and prawns, and is the only remaining site in Singapore for many other plant and animal species.

Coastal forest

Typical of this vegetation type are plants such as the Sea Teak (*Podocarpus polystachyus*), Sparrow's Mango (*Buchanania arborea*), Sea Olive (*Olea brachiata*), and other species such as *Tristaniopsis whiteana*, *Licania splendens*, *Pittosporum ferrugineum*, and *Knema globularia*. Other species can be found just behind the beach, including the Sea Lettuce (*Scaevola sericea*), Sea Poison tree (*Barringtonia sericea*), Mempari (*Pongamia pinnata*), *Guettarda speciosa*, and the herbaceous *Tacca leontopetaloides* and *Crinum asiaticum*. Examples of coastal forests can still be found on: the steep slopes behind Labrador Nature Reserve, especially behind the rocky shore; parts of Pulau Ubin, such as Tanjong Chek Jawa; the Siloso headlands of Sentosa; the rocky cliffs of St. John's Island; and other large Southern Islands, such as Lazarus Island or Pulau Pawai.

Secondary forest

The term "secondary forest" is used to describe the woody vegetation where forest had been completely cleared and has grown up afresh. This contrasts with primary forests that might have been disturbed but never been completely cleared. In general, early successional species of tropical forests are characterised by a higher tolerance for sunlight as seedlings as well as an ability to withstand lower humidity, the drying effects of wind, and higher temperatures, compared to plant species found exclusively in mature forests. A well-known type of secondary forest succession in Singapore is known as *Adinandra belukar*, because of the abundance of *Adinandra dumosa* there.

The bulk of the Central Catchment Nature Reserve is of old secondary forest and not easy to distinguish from the fragments of truly primary vegetation embedded within it. Other substantial areas of secondary forest occur on offshore islands and in military areas. Where vegetation has grown up more recently, it contains a poorer native and introduced species mix, of acacia, tembusu, rubber, and other quick-growing trees, that has not yet been enriched by further colonisation over time.

Mangroves

Mangroves grow between the low and high tide lines, typically with a muddy substrate but variable amount of sand content (affecting the tree species composition), supporting a few tree genera that have clear and specific adaptations to this environment (*Avicennia*, *Bruguiera*, *Rhizophora*, *Sonneratia*, *Xylocarpus*). The adaptations include prop roots, pneumatophores, tolerance of regular inundation and exposure, salt excretion mechanisms, propagules dispersed by water, resistance to salt, and embedding in mud. The mud or sand content of the substrate, tidal exposure regime, and salinity are important factors affecting the tree species composition. The forest has a closed canopy and little undergrowth, but where disturbed there may be a growth of the ferns *Acrostichum aureum* and *A. speciosum*, and climbers such as *Derris* and *Flagellaria*. Weeds, climbers, epiphytes, understorey, and tree species variety increase with distance away from the water and closer to a back-mangrove transition with terrestrial habitats.

Mangrove forests are possibly the world's most productive type of wetlands. People from many developing countries in tropical and sub-tropical regions often depend heavily on mangroves for their livelihood, as a wide range of forest products, including food, fibre, and medicines, can be obtained from the mangrove ecosystems. In addition to the provision of valuable resources, mangroves are known to provide physical protection to coastlines by breaking the sea waves during storm surges. It is also known that mangroves help protect seagrass beds and coral reefs from the effects of siltation. They serve as a source of food and nursery ground for a number of fish species that are important to local fisheries.

Mangroves are under threat due to the pressures exerted on the habitat from increased urbanisation and growth of the human population. In Singapore, less than five percent of the original extent of mangrove forests habitat coverage from the early 1800s remains.

Mudflats

Areas of deposition of fine sediments along the coast, in the intertidal zone and below the lowest tide, are often in a dynamic stage where they may be colonised by mangroves or remain as bare mud. They support a wide array of shallow-burrowing molluscs, polychaetes and other invertebrates, and some surface-living forms, often at very high densities. These are a food source for larger animals such as mudskippers and wading birds at low tide.

Sandy beaches

In the intertidal zone, coarse-grained deposits occur along coasts with higher wave energy. In Singapore the adjacent sandy beaches are typically narrow. Some have been lost to reclamation and the remainder is often under pressure from recreation or development. Some beaches are artificially maintained by supplementing with sand. They support a narrow range of plant and animal life. Below high tide level are molluscs, crustaceans, annelids, and a wide range of interstitial organisms.

Rocky shores

Only a few stretches of rocky shores still remain, for example at Labrador, where rocks occur along and above the tideline, in the splash zone or just above but not covered by tides; they are typically steep and include bare rock faces (in Singapore, mainly sandstone or granite), but they may also bear substantial tree growth lodged in crevices or be overshadowed by trees.

Seagrass beds

Seagrasses, amongst the very few marine angiosperms, occur in limited areas in the intertidal zone and below the low water mark. Various species are found on sandy or muddy substrates, with the species composition varying according to the water depth and bottom substrate. Historically, they have provided a food resource for the dugong, and as a habitat they support a range of small fishes, crustaceans, and annelids that move in between the fronds or in the intervening substrate.

Freshwater streams

Streams remaining in their natural condition, with undisturbed banks and bottoms, are now confined mainly to the nature reserves. Most streams in Singapore have been deepened by cutting, resulting in U-shaped channels. Ferns and other vegetation typically line the banks. There may be stilt-rooted trees, pandans, and other forest-living plants that selectively grow in wet conditions. Streams running through disturbed and cleared country, with a typically U-shaped channel, may have sandy or muddy banks that support secondary growth of grasses and shrubs. Few now remain without a canalised artificial bed of concrete.

Reservoirs

Large, artificial standing water bodies have been created by damming previously existing watercourses, or by *de novo* construction, for water retention and supply. There are now 17 reservoirs in Singapore. Their sizes, functions (for water supply), and histories (damming of a water course) are usually distinct from ponds. In the Singapore context, some have entirely artificial banks (e.g., Bedok), whereas others are fully surrounded by secondary vegetation or forest (e.g., MacRitchie).

Parks and gardens

Tended, mown fields, sports fields, and manicured lawns occur in parks or gardens. Alongside these are planted trees, flower beds, and other artificial features. Beneath the trees, the ground is typically open to allow easy visitor movement, but many parks in Singapore also contain wilderness areas and patches of vegetation, such as secondary forest and even mangroves. Planted vegetation refers to vegetation deliberately planted in designed, cultivated, and constructed green spaces. Their biodiversity potential depends heavily on the plant selection and the degree of maintenance undertaken. Overly manicured green spaces offer fewer opportunities for diverse life. Garden plants are cultivated mainly for their ornamental characteristics; hence, some may be infertile or unsuitable as food plants for wildlife, because they lack nectar or contain unpleasant secondary compounds. But others, even if foreign in origin, are able to provide nectar, seeds, fruits, leafy foods, or shelter for local wildlife.

Roadside trees

Singapore has planted more than two million trees along roads and expressways since the beginning of the movement to green the nation. While many such trees are ornamentals brought in from other regions, the current policy is to increase the proportion of native species used for planting.

Rooftops and vertical greenery

Newer technologies have created new, entirely man-made habitats for wildlife, such as greenery on walls and rooftops. This has resulted in many modified urban environments hosting a unique urban community of flora and fauna. Green outdoor walls often provide a humid and shaded environment that can support small wildlife. Their value for biodiversity enhancement depends on accessible water and the plant selection (plants that provide food and shelter). So far, little research has been done on biodiversity-enhancing measures in the tropics. However, greening walls on high-rise buildings is a challenge for all architectural and gardening professionals in terms of technology and plant selection.

Balconies and potted plants

Private gardens and container gardens along the common corridors of apartment blocks and on balconies can be important stepping-stones for native wildlife. They aid in the movement of species between disconnected areas of their natural habitat and are an important tool in biodiversity conservation. For wildlife that have adapted to survive in urban spaces, these gardens also become resting, nesting, and feeding havens in the midst of urban development and heavy human and vehicular traffic. These stepping-stones can be of any size to benefit wildlife—even high-rise corners filled with potted plants will help smaller wildlife such as sunbirds, butterflies, moths, jumping spiders, and a diversity of other jewel-like bugs. Larger planted spaces can attract and host more bird species, such as the Yellow-vented Bulbul, Black-naped Oriole, and Common Iora.

Grasslands

When left untended, grassland becomes rough with a single to a range of non-lawn grass species. Some are in dry areas, where drainage is good so that there is little or no standing freshwater even after rain, and that quickly disappears. There may be scattered shrubs such as

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Melastoma and weeds such as *Lantana*, but these occupy only a small percentage of the area. Untended rough grassland also occurs where drainage is poor and standing freshwater remains for long periods. As a result, there is often a significant admixture of sedges, tending towards freshwater swamps. There may also be scattered shrubs, such as *Dillenia suffruticosa*. Many species and individuals of low-growing weeds may occur in interstices among the grass, including local rarities such as the orchid *Liparis ferruginea*.

Conservation Techniques in Modern Singapore

This quick review of the natural and man-modified ecosystems within Singapore covers the main areas where our biological diversity exists, where it can be protected and enhanced—or alternatively degraded or eliminated. Within these ecosystems, Singapore practises an array of conservation techniques, ranging from the traditional management of protected areas to the management of individuals in small populations. All must be done within the context of a dense human population, maximising the multiple values of land, in order to bring tangible benefits to the community.

Protected areas

Singapore has: four legally protected nature reserves totalling 4.7 percent of the land area (3.7% forest, 1% reservoir surface); over 300 public parks (2.8% of total land area); and 24 administratively protected nature areas that will be retained for as long as possible.

Species protection

Within the nature reserves and parks, all plant and animal life is totally protected under the Parks and Trees Act (with the latest revisions from 2005 and now under review). Throughout Singapore, the Wild Animals and Birds Act of 1965, now under review, protects all species as defined under the act except for six potential bird pests. A full review of Singapore's legislation was given by Lye (2008). The absence of a poaching and trapping mentality, together with the availability of habitat, have enabled species at risk or declining in the region, such as the Great-billed Heron, Long-tailed Parakeet, Blue-crowned Hanging-parrot, and Straw-headed Bulbul, to maintain and even increase their core population sizes in Singapore.

Habitat restoration and enhancement

The past degradation of forests has left spots within the nature reserves that have failed to regenerate. There is an active programme to remove choking ferns and to plant trees of native species and local stock. Grassland habitat creation has been conducted for small birds, for example, at Pulau Ubin. The creation of butterfly habitats has been done at Pulau Ubin and Sungei Buloh, and a butterfly trail is under development by the Nature Society (Singapore), incorporating some of Singapore's busiest shopping areas through the city (See pages 110 to 119 by Gary Chua).

Connectivity

The Singapore landscape has been fragmented by past agriculture and settlements, roads, housing, and other infrastructure. In 1985, Singapore initiated a system of park connectors, and aims to achieve 300 kilometres of park connectors in the network by 2015. Tensions between the requirements of people and of wildlife for connectivity require that the authorities be innovative in design, species choice, planting, and maintenance as well as make use of adjoining green space to maximise the effectiveness of the network. Singapore has committed to the construction of an Eco Link, a wide forest-topped bridge across the Bukit Timah Expressway, to link two nature reserves for people and wildlife. Pre-, current-, and post-construction monitoring is being conducted to assess the effectiveness of the Eco Link. New concepts by the National Parks Board include the creation of street gardens and nature ways. The National Parks Board is now looking at the issues of connectivity and defragmentation of habitats throughout Singapore.

Species management

Within an area as small as Singapore, the management of individual species becomes feasible. A well-known recent example is the Oriental Pied Hornbill that has responded well to the provision of artificial nest sites, despite limits on the number of suitable natural cavities (See pages 130 to 135 by Robert Teo). Other native species being considered include Lesser Whistling Ducks, Oriental Magpie-robins, and sunbirds (See pages 124 to 129 by Geoffrey Davison and Subaraj Rajathurai). Artificial propagation is used mainly for rare plants, to increase their population sizes using Singapore native stock wherever possible. Native

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orchids are being produced in numbers, including epiphytes for reintroduction onto roadside trees. The techniques of mass propagation and tissue culture of orchids, developed by Singapore Botanic Gardens, can be focused on any given species that requires conservation attention. Other plant species including trees and lianes are a focus of the Plant Conservation Project under the National Parks Board and other projects by the National University of Singapore. Conversely, potential nuisance animals, such as crocodiles, monitor lizards, monkeys, civets, and crows, may require population control.

Natural and assisted recolonisation

Species thought to have returned unassisted to Singapore after a period of local extirpation include the Wild Boar, Oriental Pied Hornbill, and Red Junglefowl. The Spotted Wood Owl is a new colonist that arrived in 1985 and whose numbers have gradually increased. Pied Imperial Pigeons were probably never extirpated entirely from Singapore—they move long distances between offshore islands—but their numbers have been boosted by escaped individuals from captivity.

Urban Biodiversity Framework

The possible strategies (now in use within Singapore) for the conservation of urban biodiversity can be grouped under the following key thrusts as part of the programme to create a "City in a Garden":

- Creating world class green icons
- Achieving a pervasive green matrix
- Integrating greenery and urban infrastructure
- Infusing biodiversity into urban spaces
- Building rooted and cohesive communities
- Building capacity in green excellence

Several programmes are also available to assess the effectiveness of these programmes in returning biodiversity to the city. They include the Singapore Index of Cities' Biodiversity, Green Mark for Parks, and Green Mark for Buildings (See pages 78 to 87 by Lena Chan and Muslim Anshari).

As a result of such efforts, Singapore contains a curious and interesting mix of features. While undisturbed natural ecosystems on land have greatly diminished, those at sea have done remarkably well so far: Singapore retains more than 250 species of hard corals, in spite of being one of the world's busiest ports. The nature reserves are small, but act as a core from which biodiversity can spread to other parts of the city. In spite of high urbanisation, some species that are declining or endangered internationally have stable or increasing populations in Singapore: examples are the Straw-headed Bulbul, Great-billed Heron, and Baya Weaver. Forest-dependent species that have benefitted from the Garden City concept include the Hill Myna and Long-tailed Parakeet as lowland forest specialists, Greater Racket-tailed Drongo, and Oriental Honey-buzzard. Species that have colonised or recolonised Singapore, indicative of habitat suitability, include the Spotted Wood Owl and Red Junglefowl. Recent discoveries or rediscoveries include porcupines, leopard cats, and greater mouse-deers. Species and ecosystems that have benefitted from low disturbance levels within military areas or other sites with limited human access include the Malaysian Plover, White-faced Plover, Great-billed Heron, Lesser Adjutant stork, seagrass beds, coral reefs, mudflats, and mangroves, as well as local rarities such as *Cycas rumphii*, *Bruguiera hainesii*, and *Sonneratia caseolaris*.

Such features show that even within the constraints of small geographical areas and dense urbanisation, significant biodiversity can be retained and even increased. Singapore is in a position to contribute to broader efforts, both by retaining important populations of organisms that are declining elsewhere and by testing and applying conservation techniques that can then be implemented more broadly. Clearly the City in a Garden concept has been able to provide conditions in Singapore in which biodiversity has a continuing and increasing role to play. CG

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The rare orchid Diaenia ophrydis has been rediscovered in Singapore after more than 100 years (Photo: Lua Hock Keong).