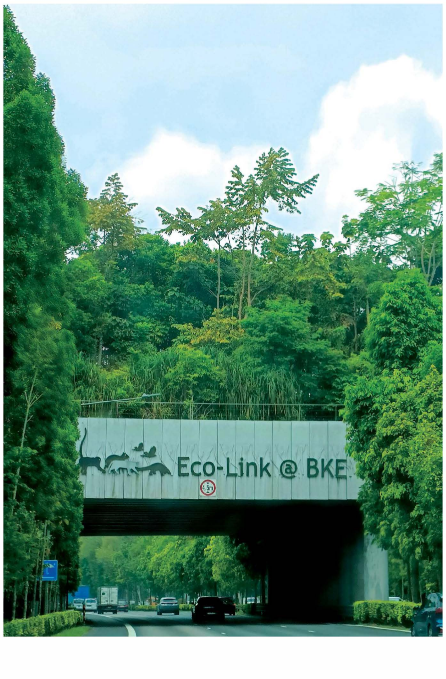
HANDBOOK ON HABITAT RESTORATION

GENERAL PRINCIPLES AND CASE STUDIES IN SINGAPORE

EDITORS LENA CHAN / DANIEL NG / LIM LIANG JIM



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Front cover: Hampstead Wetlands Park (top); Eco-Link@BKE (bottom left); Rifle Range Nature Park (bottom right)

Back cover: Multi-tiered planting of native trees and shrubs along roadside (top left); Bishan-Ang Mo Kio Park (top right); Old Mandai Road (center); Red-Wattled Lapwings at Kranji Marshes (bottom left); Jurong Lake Gardens (bottom right)

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FOREWORD

On 1 March 2019, the United Nations General Assembly declared 2021 to 2030 as the UN Decade of Ecosystem Restoration. Currently, some 56% of the world's population live in cities where natural habitats may still be found albeit as small fragments. It is imperative that cities play a significant role in achieving the objectives of the Decade of Ecosystem Restoration. While the science of restoration is still evolving, many of the demonstration projects on habitat restoration including the ones featured on the website of the UN Decade on Ecosystem Restoration (www.decadeonrestoration.org), are initiatives carried out in forested and agricultural landscapes. In the publication of an online handbook, we hope to share Singapore's experiences in habitat restoration that focuses mainly on urban ecosystems and their vicinities.

In the last decade, Singapore's National Parks Board (NParks) set forth a new paradigm in urban greening. It shifted from the provision of greenery to the restoration of nature and ecosystems; from establishing green spaces to curating green spaces for nature-based recreation, well-being, and community cohesion. As part of this undertaking, it took on a multi-disciplinary approach that encapsulated the science of landscape ecology, conservation biology, veterinary science, arboriculture, horticulture, and socio-ecology. Underlying this was a concerted effort to institutionalise the application of science and technology, and embrace an evidence-based approach in planning, conserving, and managing a hybrid novel-natural ecosystem of nature reserves, nature areas, gardens, parks, nature ways and streetscape greenery. Singapore's transformation into a City in Nature has required the application of all these skills and resources, guided by a philosophy that habitat restoration efforts must be carried out in close collaboration with the human communities that are integral to the urban ecosystem.

We had a head start in 2014, when NParks commenced a course to train officers in habitat restoration. This Handbook on Habitat Restoration is a compilation of case studies of habitat restoration implemented in 24 sites covering diverse ecosystems in Singapore. I hope it will be a useful guide to practitioners who are working on ecosystem restoration in cities worldwide, working towards successful outcomes for biodiversity conservation and countering climate change.

Kenneth Er
Chief Executive Officer
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(17 Feb 2014 to 31 May 2023)

PREFACE

Lena Chan, Daniel Ng & Lim Liang Jim

Introduction

The National Parks Board (NParks) embarked on a systematic journey of habitat restoration in 2014, with the organising of a course for NParks' officers from different divisions with diverse interdisciplinary expertise working together to discuss and explore methods of habitat restoration, enhancement, and enrichment. The first lecture was held on 19 January 2015. Over the past eight years, NParks has been implementing several habitat restoration projects at different scales, and covering a diversity of ecosystems from dryland to wetlands, terrestrial to coastal and marine, among others.

With escalating global biodiversity loss, it is imperative that remedial actions need to be activated urgently. In response, the United Nations declared 2021 to 2030 to be the Decade on Ecosystem Restoration. In addition, three critical pillars of Singapore's "City in Nature" vision are "Intensifying Nature in our Gardens and Parks"; "Restoring Nature into the Urban Landscape"; and "Strengthening Connectivity between our Green Spaces", all of which emphasise on ecological restoration.

It is, therefore, timely that NParks compiles and shares its rich experiences in habitat restoration and enhancement in a handbook that serves the objectives stated below.

Objectives of the Handbook

The objectives of the handbook are:

- To capture and distil the principles and methodologies used in habitat restoration and habitat enhancement;
- To compile case studies of projects that had been carried out in Singapore, particularly by NParks;
- To share regional and international perspectives in habitat restoration and enhancement efforts; and
- To encourage the evaluation and monitoring of habitat restoration and enhancement initiatives so that they can be improved.

History of habitat restoration and enhancement in Singapore

Habitat restoration and enhancement have been implemented by NParks for many years but on an *ad hoc* basis, that is, in response to situations rather than in a planned manner with specific objectives in mind.

Historically, habitat restoration and enhancement had been carried periodically in nature reserves, as and when required, to cover gaps caused by tree fall. There were some basic principles that were followed. It was critical that for species recovery programmes to be sustainable, they must be closely integrated with habitat restoration and enhancement. Given Singapore's unique environment, where greenery occurs in proximity to urban infrastructure, endangered and rare species can occur in areas outside the nature reserves and parks administered by NParks. Our broad strategy for conservation was thus to first try to conserve *in situ* some of these specific and localised areas with rare species, supported by *ex situ* conservation of these species via breeding programmes or translocation into appropriate sites within protected areas like the nature reserves and nature parks. In 2012, we ventured into coastline protection and mangrove restoration in Pulau Tekong, using the hybrid model of a low rock revetment interspersed with multi-species of native mangrove saplings in biodegradable pots, where the alignment was guided by mathematical modelling.

One of the key thrusts of NParks' Nature Conservation Masterplan was Habitat Restoration and Enhancement (National Parks Board, 2015). To educate and train NParks' officers on habitat restoration, the National Biodiversity Centre (NBC) developed a formal programme together with Centre for Urban Greenery and Ecology (CUGE). The first Habitat Enhancement Seminar was held on 19 January 2015 where all NParks' officers were encouraged to participate in. To put to practice the lessons learnt from the seminar, a Habitat Enhancement Workshop was conducted from 29 to 30 June 2015 for officers from several divisions, including NBC, Conservation, Parks, Planning and Policy, and Parks Design and Development. Marsiling Park (see Chapter 12) was selected where the officers applied the principles and methodologies they had distilled from Miyawaki (1999) and Elliot *et al.* (2013), resulting in the first structured habitat restoration and enhancement project. The 2nd Habitat Enhancement Seminar was held on 8 June 2016. From 10 to 11 October 2016, the 2nd Habitat Enhancement Workshop was held with another group of NParks' officers working together on a different site. This series of seminars followed by workshops continued annually.

Several more ambitious and challenging habitat restoration projects were implemented. These included, *inter alia*, the Learning Forest as a restoration of ecologically-connected wetlands (Chapter 3), the restoration of Kallang River as an ecological corridor (Chapter 9), restoration of marshes and wetlands in Kranji Marshes (Chapter 10), restoration of a diversity of ecosystems on Coney Island (Chapter 11), mangrove restoration in Pulau Ubin (Chapter 20), and Jurong Lake Gardens as a case study model for novel landscapes (Chapter 25).

Invaluable lessons can be learnt from small projects, too. A 0.58-hectare park at Fusionopolis North (Chapter 16), the HortPark Bee Trail (Chapter 17), and the artificial tidal pools (Chapter 22) demonstrate how these diverse efforts, albeit modest in size, make a discernible difference to the liveability of the areas in the vicinity and enrichment of the biodiversity.

This handbook features not only restoration works by NParks but also some projects that have been carried by researchers and agencies in collaboration with NParks (Chapters 14 and 26).

Structure of the handbook

The handbook is organised into five parts. In Part 1, habitat restoration is placed in the context of how it supports NParks' vision and mission, which evolved from Singapore being a Garden City to a City in a Garden, and the subsequent transformation into a City in Nature in Chapter 1, followed by the ecological principles and restoration methodologies that guide the habitat restoration and enhancement projects in the case studies as shared in Chapter 2. Part 2 comprises iconic projects like the Learning Forest in the Singapore Botanic Gardens (Chapter 3), and the restoration of the Kallang River in Bishan-Ang Mo Kio Park (Chapter 9). Medium-sized projects, which include habitat enhancement to support slope stabilisation at Kent Ridge Park (Chapter 15), and mangrove restoration in Pulau Ubin (Chapter 20) and Pasir Ris (Chapter 21) are grouped together in Part 3. The technologies and innovative tools that support these initiatives are assembled in Part 4. Part 5 links lessons learnt from local and global experiences and crystal-ball scans for guidance into future directions on habitat restoration and enhancement.

This handbook bears the fruit of all the hard work, discussion, inter-divisional cooperation, and innovative skills of numerous officers of NParks. Their dedication to restoring and enhancing the native ecosystems of Singapore is truly to be lauded and showcased in this handbook.

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Lena Chan

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CHAPTER 1

Habitat Restoration and Enhancement as a Thrust in the Nature Conservation Masterplan and City in Nature Vision

Lena Chan & Lim Liang Jim

Singapore's ecological history and rationale for habitat restoration

Singapore was originally covered with a diversity of tropical ecosystems, including rainforests, freshwater swamps, and mangroves until the end of the 19th century when more than 95% of Singapore's original forest cover were cleared (Corlett, 1992; Ng & Corlett, 2011).

Two important fundamental questions need to be addressed for habitat restoration. Firstly, has Singapore reached its tipping point and hence is it possible to restore its natural ecosystems? Secondly, are there benefits to restoring ecosystems and ecosystem services in urban areas to justify restoration efforts?

Despite the rapid loss of natural habitats before 1930, it is still possible to find lowland dipterocarp forests, different types of secondary forests, freshwater swamps, grasslands, mangroves, sandy beach forest, rocky beach forest, freshwater streams, intertidal mudflats, seagrass meadows, algal beds, coral reefs and other habitats in Singapore in the 21st century (Tan *et al.*, 2010). It can be inferred that a rich diversity of natural ecosystems exists in Singapore. Research on and monitoring of Bukit Timah Nature Reserve indicated that the dispersal of large-seeded plant species continued in spite of the absence of large mammals, possibly by small-mammals and birds (Lum & Ngo, 2021). The lush forest thriving on the 10-year-old Eco-Link@BKE also shows that habitat restoration efforts can assist in the re-establishment of lost habitats. The above examples affirm that Singapore has not reached its tipping point and habitat restoration can bear fruit.

The benefits of ecosystem services that are provided by green and blue spaces in urban areas are numerous (Elmqvist *et al.*, 2015), including a) microclimate regulation, b) water regulation, c) pollution reduction and health effects, d) innate and inherent values of habitats, and e) cultural services.

Habitat restoration is a key thrust of the Nature Conservation Masterplan and City in Nature

The late Mr Lee Kuan Yew planted a Mempat tree (*Cratoxylum formosum*) on 16 June 1963, marking the beginning of the tree-planting campaign that has continued since. Following this, over the last sixty years, ecosystem restoration, enhancement and species recovery have increasingly become vital components of Singapore's greening and biodiversity efforts. As an obligation of a signatory of the Convention on Biological Diversity, Singapore developed its National Biodiversity Strategy and Action Plan (NBSAP), a framework to guide its biodiversity conservation efforts that was presented in 2009. One of the actions of its first strategy, i.e., Safeguard Our Biodiversity, was to "rehabilitate areas that have previously been degraded". Keeping the momentum, the Nature Conservation Masterplan (NCMP) (National Parks Board, 2015) serves to operationalise the NBSAP.

The four thrusts of the NCMP are:

- Conservation of Key Habitats
- Habitat Enhancement, Restoration, and Species Recovery
- Applied Research in Conservation Biology and Planning; and
- Community Stewardship and Outreach in Nature

Recognising the contribution of natural ecosystems to ecological resilience, climate resilience and social resilience, NParks embarked on a new paradigm shift to transform Singapore into a City in Nature on 4 March 2020 through restoring nature into the city for livability, sustainability, and well-being.

The strategies adopted are fine-tuned from those of the NCMP:

a) Expanding the Nature Park Network
b) Intensifying nature in gardens and parks
c) Restoring nature into the urban landscape
d) Strengthening connectivity between Singapore's green spaces

Every greening initiative that Singapore has set about visioning included habitat restoration and enhancement as one of the key strategies, attesting to its pivotal role in successful biodiversity conservation. This handbook is to ensure that the rich experiences and lessons learnt from NParks and other researchers are more shared more widely. Building on current knowledge can only improve and escalate the learning curve, especially with the application of digitalisation, scientific advancement, technological and technical innovations. With the implementation of more habitat restoration initiatives, Singapore will be able to contribute positively to the UN Decade of Ecosystem Restoration and meeting targets of the Kunming-Montreal Global Biodiversity Framework that pertain to ecosystem restoration and enhancement.

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CHAPTER 2

Principles and Approaches to Habitat Restoration and Enhancement with Particular Reference to the Singapore Context

Lim Liang Jim & Lena Chan

On 4 March 2020, it was announced that the National Parks Board (NParks) will work with the community to transform Singapore into a City in Nature. This new vision builds on what Singapore has achieved as a biophilic City in a Garden. It seeks to further integrate nature into our city to strengthen Singapore's distinctiveness as a highly liveable city while mitigating the impacts of urbanisation and climate change.

As Singapore moves towards becoming a City in Nature, NParks will safeguard and extend Singapore's natural capital island-wide. This will be the next bound of urban planning to create a liveable Singapore for all. Singapore's transformation into a City in Nature will be guided by four key strategies – extending our nature park network, intensifying nature in gardens and parks, restoring nature into the built environment, and strengthening connectivity between Singapore's green spaces.

The Nature Conservation Masterplan (NCMP)

An integral part of the City in Nature vision is the Nature Conservation Master Plan (NCMP). Guided by science-based principles, the NCMP consolidates, coordinates, strengthens and intensifies Singapore's biodiversity conservation efforts (National Parks Board, 2015). These efforts will build ecological resilience through the strengthening of ecological linkages that will help us conserve our native biodiversity and ameliorate the effects of climate change.

The NCMP consists of four thrusts:

1) first, the conservation of key habitats;
2) second, habitat enhancement, restoration, and species recovery;
3) third, robust and credible research in conservation biology and planning; and
4) fourth, community stewardship and outreach in nature.

All our conservation initiatives encompass terrestrial, coastal, and marine ecosystems, at the ecosystem, species, and genetic levels.

Enhancing and restoring habitats

It is inevitable that natural landscapes in cities degrade over the years due to human activities and land use changes. With increasing evidence that biodiversity provides ecosystems that are beneficial to human health and well-being, it is essential that the functional integrity of natural sites be repaired through habitat restoration, enhancement, and creation efforts. Hence, the second thrust of the NCMP focusses on a) habitat enhancement and restoration in core areas, buffers, other greenery nodes and ecological connections, and b) species recovery.

Habitat enhancement techniques, besides being implemented in natural areas, are also applied to urban landscapes or biodiversity-impoverished sites. A trail planted with butterfly-attracting plants spans a stretch of Orchard Road, which is one of the busiest shopping areas in Singapore. A freshwater wetland habitat was restored in the Learning Forest which lies in the buffer zone of the Singapore Botanic Gardens, a UNESCO-inscribed World Heritage Site. This freshwater wetland habitat restores the hydrological process, regenerates the lowland rainforest, brings people closer to nature and serves as a refuge for threatened freshwater flora and fauna (Er *et al.*, 2017).

In January 2019, NParks unveiled the Forest Restoration Action Plan, which seeks to strengthen the resilience of our native rainforests by restoring ecological processes and enhancing biodiversity and ecological connectivity. The Action Plan also aims to assist the succession of early secondary forests to more mature and diverse rainforests over time, thereby improving habitats for biodiversity. The approach will comprise the planting of a framework of native plant species that fix nitrogen to naturally improve soil conditions and attract pollinators and dispersers. Weed species will also be removed to assist regrowth. Dominant primary rainforest species will also be introduced.

As part of the City in Nature vision, NParks will continue to curate the landscapes in gardens and parks to make them more natural. Natural designs and planting will be incorporated into new and redeveloped parks and gardens, re-creating the look and feel of Singapore's natural forests. NParks will be developing or redeveloping more than 300 hectares of parks by 2026. In addition, the waterbodies within our gardens and parks will be naturalised, where possible. Nature-based solutions will contribute towards Singapore's resilience in addressing the challenge of sea-level rise and inland flooding due to climate change.

This chapter aims to lay out the concepts and principles that guide NParks' projects now and, in the future, to restore and enhance habitats in our nature reserves, parks and other green spaces.

Habitat restoration – Six guiding concepts

The following Key Concepts are highlighted here to provide a framework to more concisely explain, define, and measure the activities and outcomes of ecological restoration practice. These concepts (listed below) are adapted from the handbook *International Standards for Practice of Ecological Restoration*, including principles and key concepts (Macdonald *et al.*, 2016) and contextualised with local examples:

1. Restoration is based on an appropriate local native reference ecosystem, taking environmental change into account.
2. Identify the target ecosystem's key attributes prior to developing long-term goals and shorter-term objectives.
3. Assist natural recovery processes wherever possible, intervening when natural recovery potential is impaired.
4. Restoration or enhancement is progressive, long-term, and adaptive.
5. Successful restoration draws on all relevant knowledge.
6. Early, genuine, and active engagement with stakeholders underpins restoration success.

Selecting an appropriate reference native ecosystem

The purpose of selecting a reference ecosystem is to optimise the potential for local species and communities to re-establish through well-targeted restoration actions to better facilitate natural processes for recovery. Selection of the reference requires careful study of the site, its surrounding biogeography, and records of the habitats and ecosystems prior to degradation.

Especially in the context of Singapore, where much of the terrestrial landscape has been subjected to numerous instances of land-use change, historical information is a valuable starting point for identifying restoration targets, while considering natural variation, and anticipated future environmental change. This exercise should not be viewed as an attempt to immobilise an ecological community at some point in time. Rather, restoration is planned in a way that informs and connects the states and conditions of an ecosystem's historic past to the ecosystems and attendant ecosystem services we intend to achieve in the future.

Identifying target ecosystems' key attributes

Identifying the target ecosystem's key attributes is important to determine the long-term targets and goals, as well as the short-term objectives of a restoration project.

Target

The target of a project can be interpreted as the specific reference ecosystem (e.g., "lowland dipterocarp forest") to which the restoration project is working towards achieving and will include a description of the key ecosystem attributes selected for monitoring and evaluation.

Goals

The goal or goals provide a finer level of focus in the planning process compared to the target. They describe the status of the target to be achieved in the medium- to long-term and, broadly, how it will be achieved. For example, in a forest restoration project where the target is a lowland dipterocarp forest in a cleared site with some remnants, the goals may be to achieve:

i. An intact and recovering composition, structure, and functionality of sites within 10 years;
ii. Effective revegetated linkages between the sites and the adjacent forest within 10 years.

Objectives

These are the changes and intermediate outcomes needed to attain the goals. For example, preliminary ecological objectives may be to achieve:

i. Reduced abundance of invasive plants to less than 1% cover within two years in the project site;
ii. Increased recruitment of native plants (at least 10 species) within two years;
iii. Increased richness (of at least 10 tree species and 10 shrubs) in any reconstructed linkages within three years.

Key attributes

Key attributes then guide the project. At the early planning stage of a project, when the reference ecosystem has been decided, site-specific attributes or sub-attributes that are specific to the ecosystem that is being restored must be identified. The attributes must be monitored using measurable indicators. Some attributes can be:

i. Absence of threats (such as contamination, land use, invasive species)
ii. Physical conditions (such as hydrological and substrate conditions)
iii. Species composition (presence of desirable plant and animal species)
iv. Structural diversity (spatial habitat diversity and food webs)

Assisting recovery

A restoration project is ideally aimed at facilitating natural recovery processes by assisting the return of appropriate cycles, flows, productivity levels and specific habitat structures and niches.

In an optimal scenario, restoration interventions should be focused on reinstating components and conditions for these processes to recommence and for the degraded ecosystem to regain its pre-degradation attributes, including its capacity for self-organisation and resilience to future stresses. The most reliable and cost-effective way to achieve this is to harness any remaining potential of species to regenerate and undertake more intensive intervention only to the extent that regeneration potential has been depleted.

Three methods can be used in restoring terrestrial forests, ranging from passive to active processes and the level of intervention required to achieve a change in the natural characteristics of the site as well as the rate of succession (Goosem & Tucker, 1995):

i. Natural regeneration (passive)
ii. Framework species method (active)
iii. Maximum diversity method (active)

Natural regeneration

Natural or assisted natural regeneration is the most passive method of restoration practices. Restoration of native plants and ecological processes to a site is reliant either solely on natural seed dispersal, or “assisted” through interventions other than planting. This method may be applied for sites occurring next to an existing established patch of mature forest.

A critical component of assisted natural regeneration is to manage any factors which hinder natural recruitment and regrowth of desirable flora. In the local context, management of invasive exotic weed species such as *Dioscorea sansibarensis* is a key factor in reforestation projects in our nature parks and nature reserves (Fig. 1).

Fig. 1. *Dioscorea* clearance with the community at Rifle Range Nature Park. (Photo credit: Cheryl Chia)

Other simple interventions for assisted natural regeneration include installing appropriate perches for dispersers such as birds to rest between flights. Retaining a sufficient number of pre-existing trees on the project site is recommended, as trees offer safe spaces for foraging, roosting, and nesting for birdlife. Single trees or small groupings of trees or large shrubs can be focal points for regeneration when birds or other dispersers deposit seeds beneath.

In the case of abandoned coastal fish or prawn farms established adjacent to mangrove habitats, assisted natural regeneration can employed with significant success. For example, a disused prawn pond in Pulau Ubin was cleared of invasive vegetation in 2002, and a retaining bund was broken down to allow recruitment of mangrove seedlings through natural hydrological processes. Within 10 years, a young mangrove forest habitat had been successfully re-established on the project site, with minimal intervention (Fig. 2).

Figs. 2. (A) Disused prawn pond in Chek Jawa, 2002; (B) Mangroves re-established on site, 2012. (Image credit: Google Earth)

Framework species method

The framework species method is one of the most commonly applied methods for reforestation in the region. This method involves planting mixtures of between 20 to 40 native forest tree species to achieve rapid species recruitment in restoration plots. By planting the least number of trees necessary to shade out invasive weeds and yet facilitate natural seed dispersal mechanisms, this helps to accelerate the recovery of biodiversity with minimum intervention.

When implemented in compromised sites which are either adjacent or very near to the target forest type with seeds and dispersers present, the framework species method is enhanced by the ability of natural dispersal and recruitment to allow for relatively quick re-establishment of forest structure and functioning as well as to create conditions on the forest floor that are conducive to the seed germination and seedling establishment. Fig. 3 illustrates how the application of the framework species method results eventually in a functioning restored forest ecosystem.

The species selected to plant for the framework species method should ideally meet certain ecological features or characteristics (Crome, 1975; Goosem & Tucker, 1995; Tucker & Simmons, 2004). These features include:

i. Tolerance of open conditions – Native forest trees that can tolerate exposure to full sun as well as be able to grow in degraded soils are more suitable.

ii. Ability to attract seed dispersers – Plant species that produce fruits that are attractive to frugivorous birds and mammals are preferable. Some desirable characteristics of the fruits include seeds of convenient size for animal dispersal; annual or regular fruiting or masting; production of fruits in abundance; and bearing significant dietary reward for animals.

iii. Early production of flowers and fruits – For enhanced dispersion, trees that begin producing flowers and fruits between three and eight years after planting should be included in the selection.

iv. Keystone species – Native species of figs (*Ficus* spp.) are important keystone species that attract a wide variety of faunal dispersers throughout the year. Different species of figs fruit at different times of the year and thereby allow for constant and regular resource for wildlife at the restoration site.

v. Ease of germination – Plants which are easy to collect, germinate and can produce abundant seed crops are good choices for restoration projects. These could also include native species which have become rare through habitat loss but can germinate easily.

vi. Rapid or persistent growth – It is recommended that pioneer and early successional species comprise 30% of a framework species plant selection – these species grow rapidly and attract bird and mammal dispersers. They will also quickly establish a microclimate more conducive to the survival and growth of late successional rainforest plants.

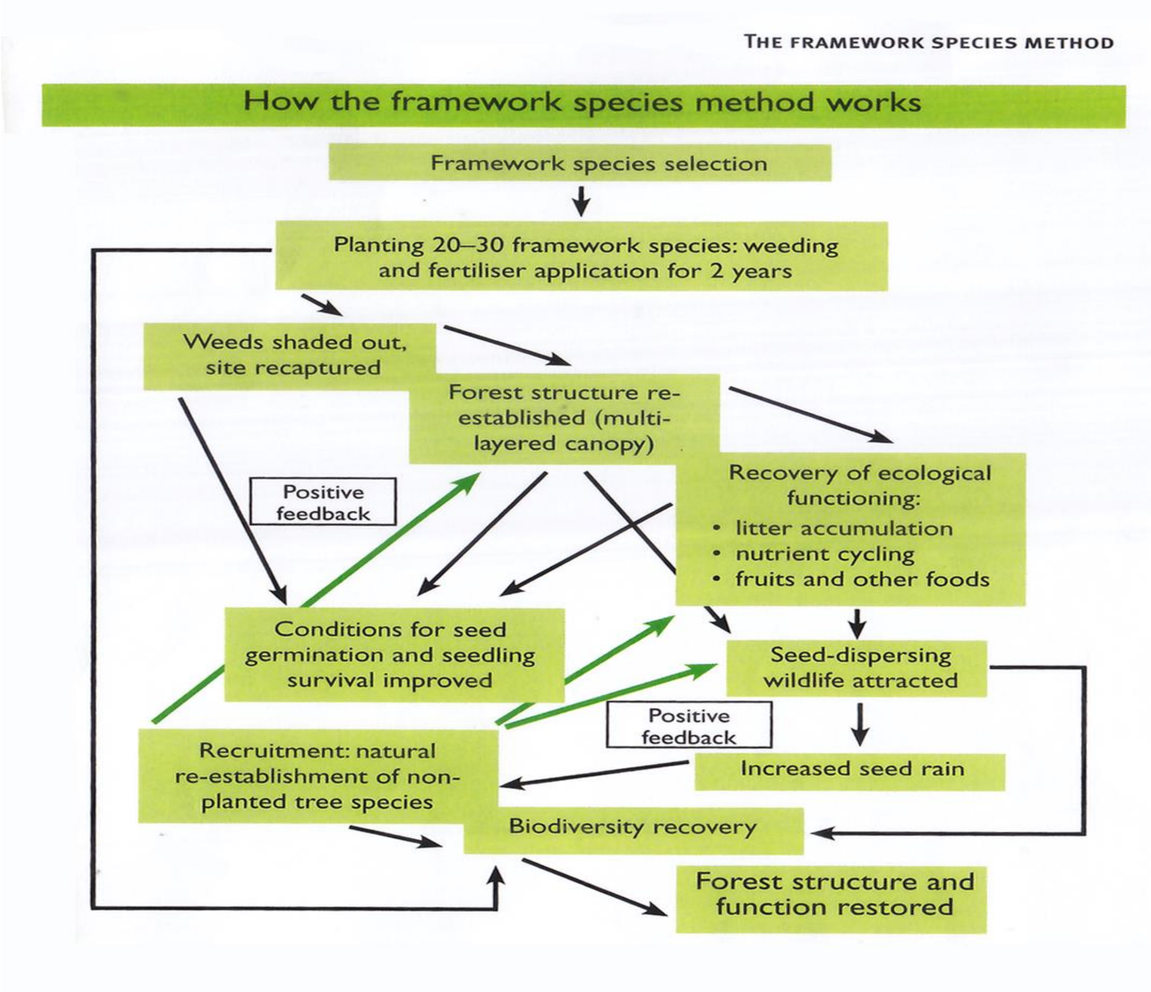

Fig. 3. Processes of the framework species method. (Source: Elliott *et al.*, 2019)

Maximum diversity method

The maximum diversity method of forest restoration necessitates the most amount of intervention and management. Most often applied in smaller sites which are isolated and not near to target forests or ecosystems, this method attempts to re-create the tree species composition of climax forest from the outset, by intensive site preparation and a single planting event featuring up to 60 species from the target habitat spaced closely apart.

The maximum diversity method is used especially when natural seed dispersal cannot be relied on to be recruited at and to replenish the restoration site at a satisfactory rate. This could be due to either the site being too far away from the seed-dispersal distance of appropriate seed trees, or being where dispersers such as birds and mammals are rare. In this case, intensive tree-planting with high species richness at the beginning of the restoration process ensures optimum biodiversity from the start.

In the maximum diversity method, intensive and consistent management efforts have to be factored into the planning process. As these sites tend to be small and quite distant from "source" habitats, they are affected by all the issues of forest fragmentation such as edge effects, vulnerability to invasive weeds and dehydration. The substrate for planting may require heavy fertilisation and mulching; planted trees require close spacing to compensate for the delay in canopy closure and to shade out weeds; and a weeding and invasive species management programme has to be implemented. Nursery capacity for the germination and supply for the large number of species and individual trees required for this method will also need to be factored in. Given the need for appropriate resourcing and sustained intervention over the short-to-medium term, the maximum diversity method is generally applied only in particular circumstances, for example in urban forestry where source habitats are far removed from the site.

Progressive, long-term, adaptive management

It may take decades for a habitat restoration project to attain its ultimate objective. This is to be expected largely because of the long-term nature of some recovery processes. Other factors that may affect the time needed include an insufficiency of restoration resources, technology, or knowledge at the time of implementation; or the presence of factors or drivers outside the site that require a great deal of time and negotiation to resolve.

Recognising that full recovery will take time is an incentive for managers to adopt a policy of continuous improvement. A key strategy for continuous improvement is through a standard adaptive management process. Illustrated below (Fig. 4), adaptive management is a simple, cyclical set of management guidelines that map out a long-term process of planning, implementation and monitoring that will then inform future improvements (Wiens *et al.*, 2017):

i. **Planning:** The process whereby the problem is defined; goals and objectives are set; hypotheses and linkages between actions and goals are formulated; and pilot sites are selected.
ii. **Implementation:** Design and implementation of a restoration or enhancement plan on a selected site; design and implementation of a long-term monitoring programme.
iii. **Monitoring and evaluation:** Data gathering; analysis and evaluation of data; communicating and reporting the results; and informing any adaptation of management processes for the site.

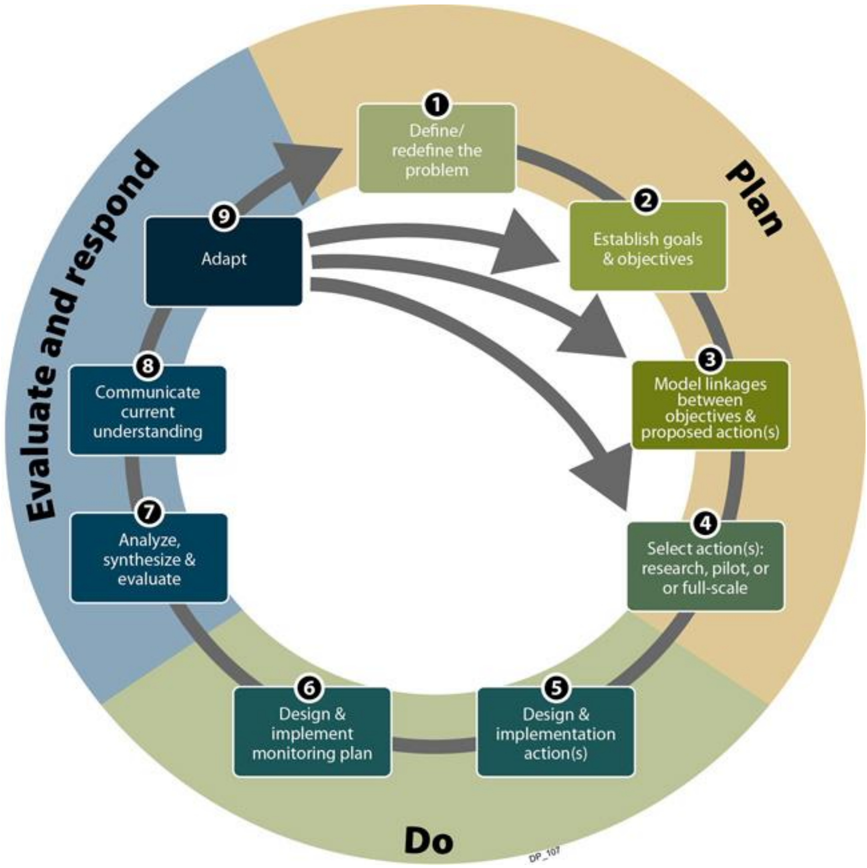

Fig. 4. Nine-stage framework for adaptive management. (Source: Wiens *et al.*, 2017)

Adaptive management is based on clear goals and an assumed set of operating objectives that may need to be adjusted by 'trial and error'. Using the best available knowledge, skills, and technology, actions are implemented according to these identified goals and objectives, and records are made of success, failures, and potential for improvement.

These lessons then form a basis for the next round of 'improvements'. Adaptive management can and should be a standard approach for any ecological restoration project.

Monitoring the responses of an ecosystem to restoration actions is essential to:

1. provide evidence to stakeholders that specific goals are being achieved according to plan;
2. identify whether the actions are working or need to be modified (adaptive management); and
3. answer specific questions (e.g., to evaluate particular measures or which organisms or processes are returning to the ecosystem).

Monitoring plans should be included in project plans to ensure that goals are clearly considered and objectives are measurable. Information on the baseline condition of a project must be collected prior to any changes triggered by restoration activities.

Methods to organise the data that indicate progressive recovery of an ecosystem include the "5-star system", which helps to identify the level to which the project goals are being achieved and to foster increased ambition for the future.

The stages of achievement of project goals can thereafter be illustrated in the form of a "recovery wheel" (Fig. 5), a template which illustrates the degree to which the ecosystem under treatment is recovering over time. A manager with a high level of familiarity with the goals, objectives and site-specific indicators set for the project and the recovery levels achieved to date can shade the segments for each sub-attribute after formal or informal evaluation.

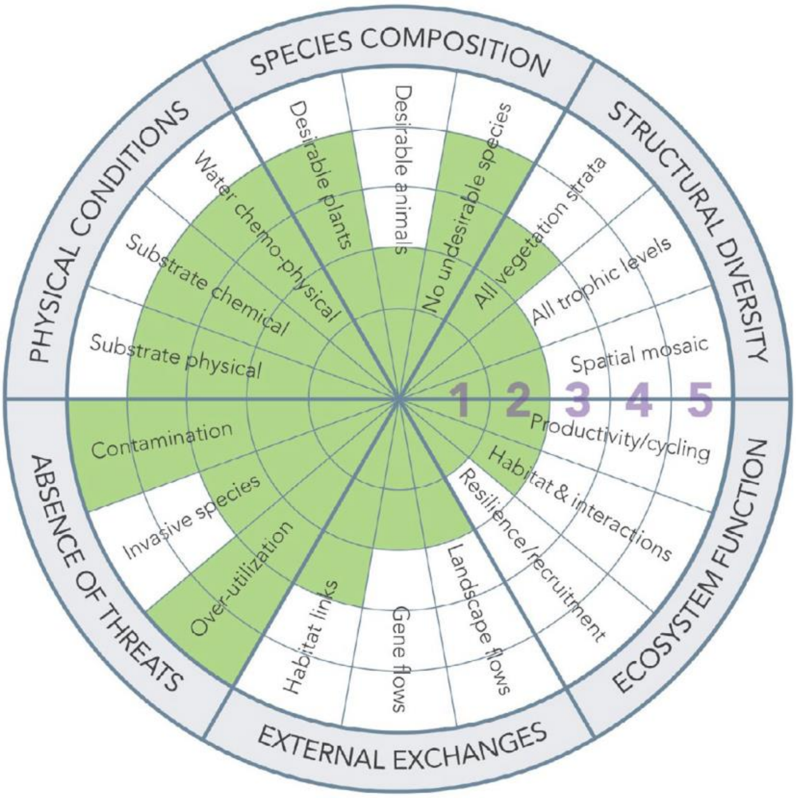

Fig. 5. A sample "recovery wheel" where the project manager for a habitat restoration effort can illustrate progressive stages of improvement in the restored ecosystem. (Source: Macdonald *et al.*, 2016)

Drawing on all relevant knowledge

Restoration ecology is not a singular field of science. It focuses on questions relevant to the practice of ecological restoration, which in turn is also informed by basic and applied ecology, conservation biology, conservation genetics and landscape ecology, hydrology, engineering, social sciences, and even economics. Implementation of restoration projects also require skills in landscape design and landscape architecture.

Monitoring of restored plots to track the success of the restoration strategy and implementation is essential. Further research (best carried out in collaboration with researchers) into restoration projects can also improve our understanding of how an ecosystem is assembled and what may be the critical minimum conditions needed to enable an ecosystem to continue its own recovery processes unaided (complete with characteristic resistance and resilience to stresses).

There is also an emerging need for scientific methodology to assist with assessing the potential of a plant or animal population to adapt effectively to anthropogenically-induced climate change.

Engaging stakeholders

Restoration and planting can provide a powerful vehicle for encouraging positive and restorative attitudes toward ecosystems and the natural world in general. Under our new City in Nature vision, stakeholder engagement and stewardship of our green spaces is a critical component of building social resilience through nature. Moving forward, conserving species, and restoring ecosystems depend upon recognition of the expectations and interests of stakeholders such as nature advocates, and involvement by all stakeholders in finding solutions to ensure that ecosystems remain resilient and the public find suitable avenues to act as stewards of our natural heritage.

Engaging stakeholders early in the planning stages of a park or forest restoration project will help to establish some key data that citizen scientists can help provide. For example, in the restoration and development of the Thomson Nature Park, the Raffles' Banded Langur Working Group (comprising members from NParks, as well as experts in the ecology of the critically endangered Raffles' Banded Langur) provided inputs for the ecological connectivity of the Nature Park and the appropriate interventions to allow arboreal species to cross between the Nature Park and the Central Catchment Nature Reserve.

In the implementation phase, volunteers can be engaged in the restoration project, by participating in planting or invasive species clearance as part of the Forest Restoration Action Plan, or the One Million Trees Movement (Fig. 6).

Fig. 6. Volunteers participating in a Forest Restoration Action Plan replanting effort.

Conclusion

In conclusion, to successfully implement a project to either enhance or restore a habitat in the context of a highly urbanised tropical city-state such as Singapore, practitioners should be keenly aware of certain fundamentals:

1) Understanding the general environment of the project site – its ecological and geographical history, as well as proximity to nearby habitats;
2) Setting a target for a desired end-state based on appropriate target habitats;
3) Selecting the appropriate level of intervention to achieve the end-state, based on long-term, adaptive tracking, and monitoring of indicators; and
4) Activating stakeholders for a collective effort in implementing the overall plan.

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CHAPTER 3

The Learning Forest: A Habitat Restoration Project that Ecologically Connects with the Singapore Botanic Gardens Rainforest

Kenneth Er, Shee Zhi Qiang, Jason Wright, Elango Velautham & Angelia Sia

The idea of visiting a lowland rainforest and freshwater wetland forest conjures images of having to trek through swarms of biting insects and knee-deep mud – hardly an experience that people without an inherent love of nature would be drawn to. The Learning Forest at the Singapore Botanic Gardens is a habitat restoration project that transforms the concept of these biologically rich yet previously inaccessible habitats. The process began with understanding the various ecological processes present and implementing strategies to strengthen them. The next stage involved overlaying an aesthetic layer to showcase the most magnificent attributes of the habitat for the visitors' delight. The final phase was to introduce recreational amenities to ensure that these habitats became easily accessible to all visitors.

Conceptualising the Learning Forest

The 10-hectare Learning Forest lies at the heart of the Tyersall-Gallop Core, which is the fourth core of the Singapore Botanic Gardens (Fig. 1). The other three cores are a) the heritage Tanglin Core, b) the Central Core hosting the tourist attractions, and c) the educational and discovery zone of the Bukit Timah Core. Envisioned as a living laboratory in a vibrant forest ecosystem, the Learning Forest enhances the Gardens' capacity for research and education and provides the public with opportunities to learn about forest ecology in an experiential setting. It also plays an important role as part of the buffer zone for the Singapore Botanic Gardens UNESCO World Heritage Site.

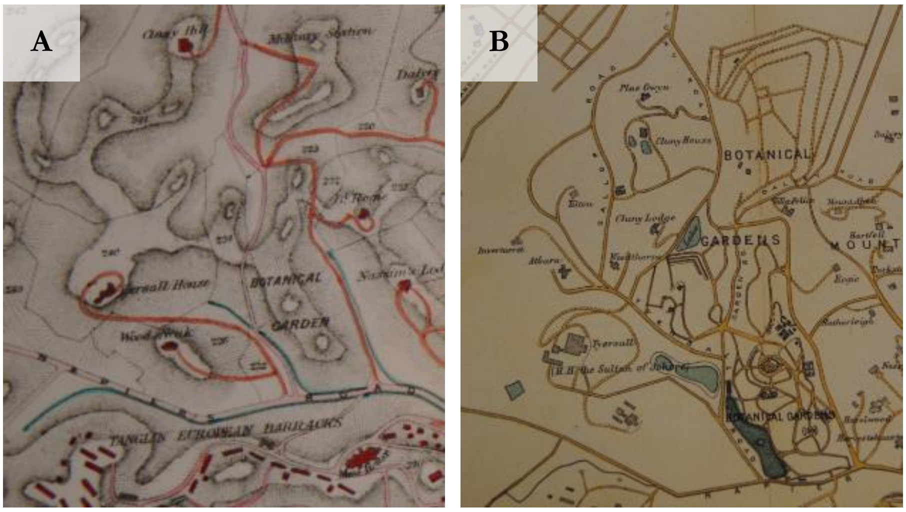
Fig. 1. The Learning Forest lies at the heart of the conservation core of the Singapore Botanic Gardens and plays an important role as part of the buffer zone for the UNESCO World Heritage Site.

The Learning Forest is a conservation project that involves the restoration of a lowland rainforest and a freshwater wetland forest. Home to over 700 species of plants, it is an exposition of the region's botanical heritage, including over 300 species of rainforest trees, 50 species of wild fruit trees, 30 species of bamboo, 30 species of climbing plants and 25 species of native orchids. However, the Learning Forest is much more than an impressive botanical collection – it elevates the concept of a botanical garden from conserving just individual plant species to conserving entire habitats, creating a unique, refreshing experience in the process.

Restoring a freshwater wetland

Swan Lake, in the historic Tanglin Core of the Singapore Botanic Gardens, is Singapore's oldest man-made lake. It was constructed in a low-lying, perpetually waterlogged part of the Gardens that was formerly freshwater wetland forest. This unique and increasingly threatened habitat used to occupy a broad swathe stretching from the northern half of the Learning Forest into the Tanglin Core. The Keppel Discovery Wetlands is a restoration of this original habitat.

Historical maps of the area dating as far back as the 1860s demonstrate how land use has evolved over the past 150 years (Fig. 2). Some of the oldest maps document the early years of the Singapore Botanic Gardens and show a stream flowing from the Learning Forest into the area now occupied by Swan Lake. The stream was converted into a series of ponds by the early 20th century but by 1924, the ponds had all but disappeared from the maps. By further analysis of the topography of the area, the Singapore Botanic Gardens was able to identify the watershed for Swan Lake and thus estimate the previous extent of the wetland (Fig. 3).



Figs. 2. These maps of the area now occupied by the Learning Forest show how the wetlands have changed from (A) a stream in 1860 to (B) a series of ponds in 1913. (Photo credit: National University of Singapore Central Library)

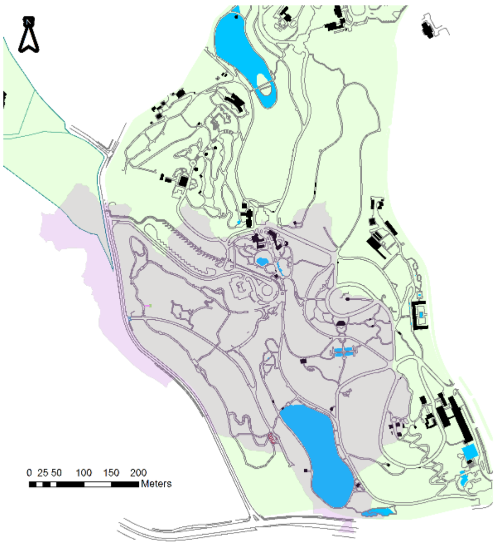


Fig. 3. The catchment area for Swan Lake is shaded in purple. The watershed analysis shows that most of the Learning Forest serves as the water source for Swan Lake.

This background information became the basis of the design of the Keppel Discovery Wetlands to function as the constant source of clean water to Swan Lake. As the Wetlands are fed by a natural spring that produces up to 90 m^3 of water per day (sufficient to fill an Olympic-sized swimming pool in a month), the team, using the Sustainable Drainage Systems (Wright & Yu, 2022), created a series of bioswales and siltation ponds to channel rainwater falling from the catchment area through the Dell and into Swan Lake (Fig. 4).

Fig. 4. Rainwater falling onto the catchment area of the Wetlands is channelled through a series of bioswales and siltation ponds, eventually finding its way through the Dell and into Swan Lake.

The Keppel Discovery Wetlands is home to remnant populations of wetland species. These include not only plants such as Penarahan Pianggu (*Horsfieldia irya*) and Nibung Palm (*Oncosperma tigillarium*), but also fauna that are dependent on freshwater wetland forests, such as the Malayan Giant Frog (*Limnonectes blythii*) and Malayan Box Terrapin (*Cuora amboinensis*).

The restored wetlands have been curated to bring out the rich diversity of freshwater plant communities in Southeast Asia. Key features include the Orchid Islands, Botanists' Boardwalk and Pulai Marsh, all of which are linked by a Discovery Trail (Fig. 5–10). This trail traces the expeditions of EJH Corner, a former assistant director of the Singapore Botanic Gardens, who explored the freshwater wetland ecosystems of the Malay Peninsula. Visitors can experience travel through a range of riverine vegetation belts, travelling through a stand of Putat trees (*Barringtonia* spp.) that bear fruits in various shapes and sizes, impenetrable thickets of Pandan (*Pandanus* spp.) up to four storeys high and sandy banks of Pelawan (*Tristaniopsis* spp.) with colourful bark.

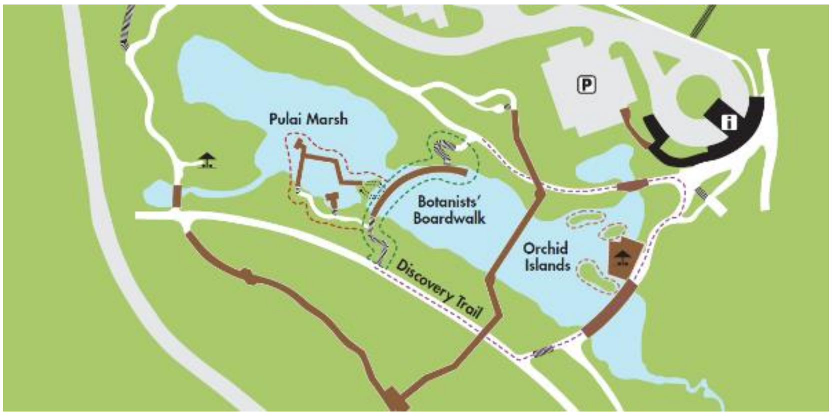


Fig. 5. The Keppel Discovery Wetlands offers three carefully curated features, all linked together by a Discovery Trail.

Fig. 6. The Botanists' Boardwalk showcases plants named after famous botanists in the history of the Singapore Botanic Gardens. (Photo credit: Shee Zhi Qiang)

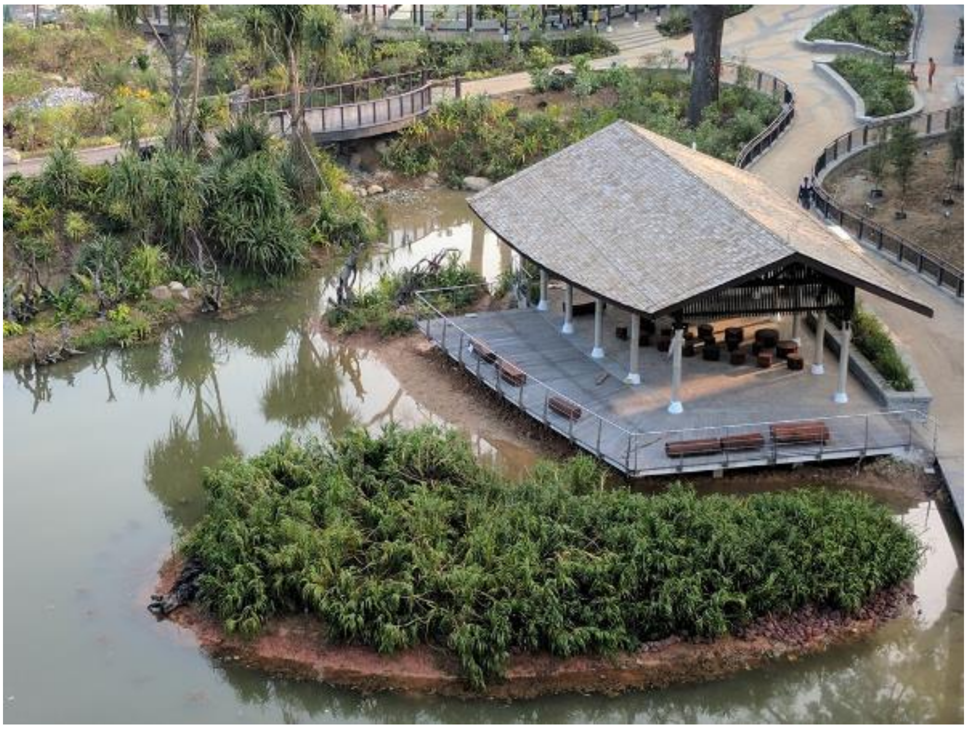


Fig. 7. The Orchid Islands at the Keppel Discovery Wetlands. The world's largest collection of Tiger Orchids is in the foreground, while the islands in the background feature both epiphytic and ground-dwelling species of threatened wetland orchids. (Photo credit: Shee Zhi Qiang)

Fig. 8. Pulai Marsh serves as a refuge for the threatened flora and fauna of freshwater wetlands. (Photo credit: Shee Zhi Qiang)

Fig. 9. The Putat-belt along the Discovery Trail mimics a riverine vegetation belt described by EJH Corner. The various species of Putat trees bear fruits in various shapes and sizes. (Photo credit: Shee Zhi Qiang)

Fig. 10. Visitors can appreciate the wide variety of bark colours exhibited by Pelawan trees on this sandy bank above the Keppel Discovery Wetlands. (Photo credit: Shee Zhi Qiang)

Regenerating the lowland rainforest

When the Singapore Botanic Gardens initiated the project in 2009, the lowland rainforest was infested with invasive weeds, such as Panama Rubber (*Castilla elastica*), African Oil Palm (*Elaeis guineensis*) and Zanzibar Yam (*Dioscorea sansibarensis*). An intensive habitat enhancement programme was undertaken using an adaptation of the Framework Species Method (Fig. 11). Invasive plants were selectively thinned out and replaced with forest species native to the region.

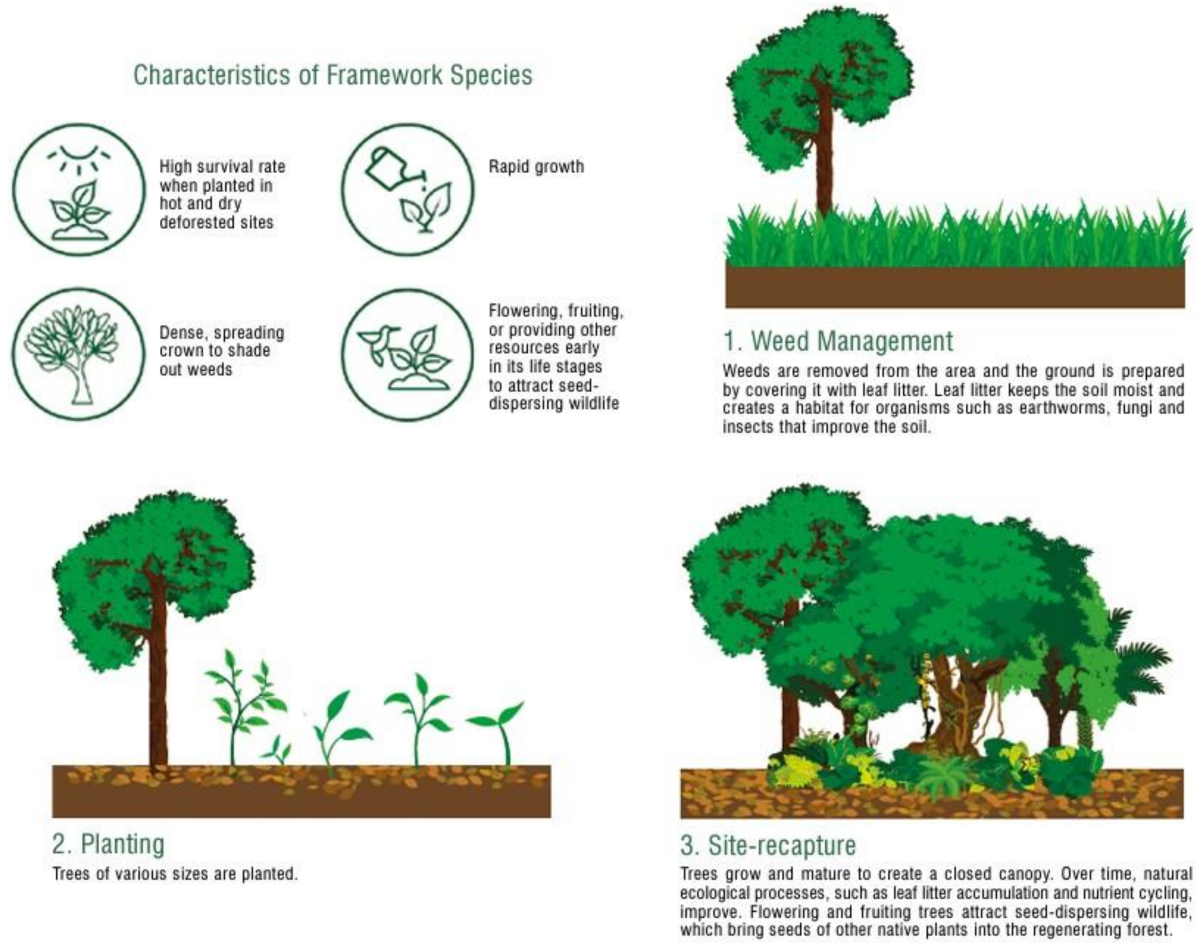


Fig. 11. An illustrated summary of the Framework Species Method of reforestation, adapted to the Singapore Botanic Gardens Learning Forest.

The first trees to be planted were relatively fast-growing species, such as Meranti Tembaga (*Rubroshorea leprosula*), Sepetir (*Sindora wallichii*) and Cengal Pasir (*Hopea odorata*). Where possible, semi-mature trees of up to 15 m tall were transplanted with much of their crown intact to form an instant canopy (Fig. 12). This helped to regulate the microclimate in the understorey, maintaining the conditions of high humidity and low light that are most amenable to the growth of shade-tolerant species found only in climax forests.

Figs. 12. (A) A reforestation site planted with semi-mature specimens of Meranti Tembaga (*Rubroshorea leprosula*), Sepetir (*Sindora wallichii*) and Cengal Pasir (*Hopea odorata*) in 2016. (B) The same site in 2019, showing the succession of vegetation as canopy cover increases. In the understorey, light-demanding species such as Balik Angin (*Mallotus paniculatus*) and wild bananas (*Musa* spp.) have been replaced by more shade-tolerant species such as Medang Kelawar (*Prunus polystachya*) and fan palms (*Licuala* spp.). (Photo credit: Shee Zhi Qiang)

The lowland rainforest today is dominated by mature specimens of Tembusu (*Cyrtophyllum fragrans*), Jambu Laut (*Syzygium grande*) and Giant Mahang (*Macaranga gigantea*), with isolated populations of Medang (*Litsea elliptica*) and Buah Kenari (*Canarium vulgare*). The oldest of these trees is estimated to be just over a century in age and they form a continuous canopy about 30 m high.

The SPH Walk of Giants, an elevated walkway, was built to take visitors from the forest floor up into the canopy of these forest giants. The focal point of the Walk of Giants is the 8 m-high Canopy Web, which wraps around two century-old Tembusu trees and creates the experience of moving about their canopies (Fig. 13). The two trees belong to a row of Tembusu trees that were originally planted to line the old Tyersall Avenue. While sitting on the Canopy Web, one may catch a glimpse of Swan Lake across the old road, as if looking back in time (Fig. 14). The Canopy Web was specially designed to accommodate the multi-stemmed form of the Tembusu trees and most of the structure supporting it was also built on the old road, thus avoiding damage to tree roots.

Fig. 13. The Canopy Web creates the experience of moving about the canopy of a forest giant. (Photo credit: Shee Zhi Qiang)

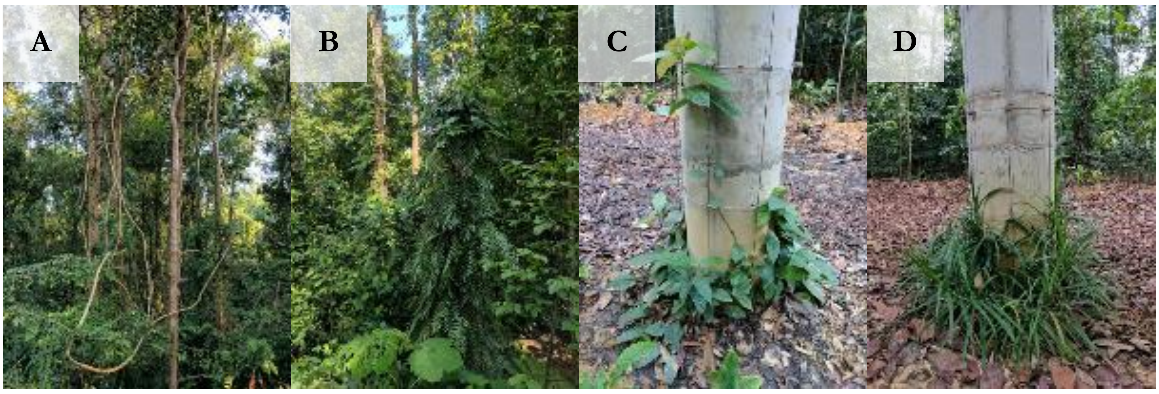
The Canopy Web is built on much lower ground than the rest of the Walk of Giants, allowing visitors to gain ground gradually as the forest floor drops away below them. Besides facilitating universal access, the gentle grade encourages appreciation of the forest at a comfortable pace. The many layers of the rainforest can be explored from top to bottom within the 260 m loop of the Walk of Giants (Fig. 14).

Fig. 14. The SPH Walk of Giants takes visitors on a journey through the many layers of the rainforest, from the forest floor to the top of the canopy. (Photo credit: Shee Zhi Qiang)

Starting from the forest floor, palms in myriad shapes and sizes can be found, including all four known species of Joey Palm (*Johannesteijsmannia*), a genus of understorey palms native only to some parts of Southeast Asia (Fig. 15). Massive clumps of the slow-growing Palas Fan Palm (*Licuala ferruginea*) bear testament to the maturity and complexity of the regenerating forest. Further along, the bright orange leaf shafts of the Ibul (*Orania sylvicola*) and the Endau Fan Palm (*Livistona endauensis*) catch the eye.

Figs. 15. (A) Joey Palms, (B) Fan Palms and (C) the Ibul are just among the wide variety of palm species at the Learning Forest. (Photo credit: Shee Zhi Qiang)

Around the bend, visitors entering the subcanopy layer are surrounded by large woody climbers such as Akar Ipoh (*Indorouchera griffithiana*) and more delicate plants, such as the Climbing Fern (*Stenochlaena palustris*) (Fig. 16). A peek at the columns supporting the Walk of Giants reveals that they are planted up with over 20 native climber species, such as the Sepedih (*Ficus sagittata*) and Climbing Pandan (*Freycinetia sumatrana*). This part of the forest is frequented by forest birds such as the Banded Woodpecker (*Picus miniaceus*) and Greater Racket-tailed Drongo (*Dicrurus paradiseus*) during the day and by forest specialist bats such as the Whiskered Myotis (*Myotis muricola*) at night.



Figs. 16. (A) The Akar Ipoh and (B) Climbing Fern are commonly seen around the Walk of Giants, while other rarer species, such as (C) the Sepedih and (D) Climbing Pandan, are planted around the columns supporting the walkway. (Photo credit: Shee Zhi Qiang)

Finally, what would the Walk of Giants be without the giants themselves? Mature secondary forest trees such as the Tembusu and Jambu Laut now tower over the elevated walkway at heights of up to 30 m. Much care and effort were taken to avoid them where possible and much effort was made to transplant those that could not be avoided (Fig. 17). However, the real stars of the show are the saplings of the true forest giants, such as *Richetia faguetiana* and *Richetia gibbosa*, which can exceed 90 m in height – taller than a 30-storey building! They will take hundreds of years to grow to that majestic size, underscoring the Singapore Botanic Gardens' long-term commitment to conservation.

Figs. 17. Mature native trees were transplanted where possible, such as (A) the Medang, (B) Jambu Laut and (C) Angsana. (Photo credit: Shee Zhi Qiang)

Creating an immersive experience

The Learning Forest represents a landmark approach in creating an aesthetically attractive and ecologically rich ecosystem from a previously inaccessible nature area, by deconstructing natural habitats and curating their associated vegetation assemblages. What sets the Learning Forest apart from many other nature conservation sites is its location within a major visitor attraction, the Singapore Botanic Gardens, which receives over five million visitors annually. Creating the Learning Forest required an approach where aesthetic appeal, accessibility and comfort are key design features. The project represents the next step for inculcating a love of nature for all visitors, and serves as a benchmark for future nature conservation projects within the urban environment.

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CHAPTER 4
Forest Restoration Action Plan

Rachel Tan, Sharon Chan, Adrian Loo & Tan Boxin

Introduction to the Action Plan

The Forest Restoration Action Plan (FRAP), part of the NParks Nature Conservation Masterplan (NCMP), was launched in January 2019. It was formulated to chart the restoration that would be undertaken over the next 10 years to regenerate the secondary forests in the buffer parks surrounding Singapore's nature reserves, as well as disturbed patches within the reserves and core biodiversity areas, including the four nature reserves and Pulau Ubin. This would assist our forests to approximate a mature forest landscape in species and structure over time.

FRAP also seeks to restore ecological processes and functions by enhancing the biodiversity and ecological connectivity in these areas through a science-based approach. It aims to improve the habitats for our native biodiversity as well as strengthen the resilience of our forests to climate change and other anthropogenic pressures. As of April 2023, a total of 398,238 native trees and shrubs have been planted.

Safeguards our core habitats

Under FRAP, NParks is focusing on intensifying our forest restoration efforts across the three Nature Park Networks – Central Nature Park Network, Sungei Buloh Nature Park Network and Labrador Nature Park Network. All three networks serve to protect the nature reserves from the impact of urbanisation and reduce visitorship pressure on the reserves, whilst providing more green spaces for all to enjoy nature-based recreation. They also provide extended habitat and enhanced ecological connectivity for our biodiversity.

The Central Nature Park Network is composed of eight nature parks that buffer the Bukit Timah and Central Catchment Nature Reserves, including Rifle Range Nature Park (66 hectares) which was opened in 2022. Constituting a mere 0.23% of Singapore's land area, Bukit Timah Nature Reserve (163 hectares) alone contains more than 50% of Singapore's native flora and fauna (Chan & Davison, 2019). The primary and mature secondary rainforest habitats provided by our nature reserves are home to many endangered species, and serve as important refugia for rare species that have been rediscovered in recent years through heightened survey efforts (Chong *et al.*, 2018; Ho *et al.*, 2018; Lim *et al.*, 2019). The extended habitats provided by the nature parks are also crucial in supporting the populations of our native species, a point that will be further explored in the 'case studies' section.

The Sungei Buloh Nature Park Network, which buffers Sungei Buloh Wetland Reserve, comprises important core habitats such as the Mandai Mangrove and Mudflat and Kranji Marshes, nature parks and eco-corridors, and nature areas such as Jalan Gemala Marshland and Kranji Reservoir Marshes. Covering over 400 hectares, which is more than triple the size of the Wetland Reserve, this network will safeguard a variety of complementary wetland habitats, including mangroves, mudflats, and freshwater marshes, strengthening the conservation of Singapore's wetland biodiversity. As wetland habitats provide a wide variety of ecosystem services such as serving as a food source and nursery ground for numerous marine organisms, storing carbon, and mitigating coastal erosion, their conservation plays a key role in bolstering Singapore's resilience against the effects of climate change.

The Labrador Nature Park Network is the latest addition that was announced in 2022. This network comprises more than 200 hectares of green spaces and 40 kilometres of trails, park connectors and nature ways, to expand our natural capital and enhance the connectivity between our green spaces. This covers the southern part of Singapore, including Labrador Nature Reserve, West Coast Park, Kent Ridge Park, HortPark, Telok Blangah Hill Park and Mount Faber Park. Labrador Nature Reserve, located at the southern tip of Singapore, is one of the last few coastal hill forests on mainland Singapore with rich biodiversity. Conservation value of such habitat is high as it is getting increasingly rare in Singapore. As part of the Labrador Nature Park Network, new nature parks such as Berlayer Creek Nature Park and Labrador Nature Park will act as a buffer to the 10-hectare coastal hill forest in Labrador Nature Reserve. Together with ongoing habitat enhancement works, this will enhance the ecological connectivity between Labrador Nature Reserve and its surrounding green spaces. This connectivity is carefully planned and guided by NParks Ecological Profiling Exercise.

The science underlying restoration efforts

Decades of rapid urbanisation have taken a heavy toll on Singapore's forests. Primary rainforests, now fragmented across the island, cover only 0.16% of Singapore's land area, while mature secondary forests and young secondary forests make up only 1.37% and 19.64% of land area respectively (Yee *et al.*, 2011). Research has shown that Singapore's secondary forests are regenerating at a very slow pace, with the structure and composition of mature secondary forests contrasting starkly with those of primary forests even after more than a century of recovery (Chua *et al.*, 2013; Goldsmith *et al.*, 2011). Forest succession is likely hindered by the lack of seedling recruitment and the persistence of early successional species. Restoration efforts will therefore go a long way in accelerating forest regeneration and thereby the recovery of biodiversity and ecosystem functioning.

Another obstacle to natural regeneration is the dominance of exotic plant species in abandoned-land forests, defined by Yee *et al.* (2016) as forests regenerated on land formerly used for plantations or village settlements (kampungs) that were vacated with the mature trees left on site. As many of the nature parks in Singapore fall into this category, their forested areas are mostly dominated by exotic species such as Rubber (*Hevea brasiliensis*), African Tulip (*Spathodea campanulata*), Albizia (*Falcataria moluccana*), Oil Palm (*Elaeis guineensis*), fruit trees, and ornamental plants, and tend to have compacted and degraded soils (Yee *et al.*, 2016). While some regeneration is underway given their proximity to the nature reserves, they still lack the abundance and diversity of native species needed for succession to take place. These forests may hence require intervention to help them mature into native-dominated secondary forests (Shono *et al.*, 2006, 2007a; 2007b).

Forest restoration methods

FRAP utilises a science-based approach where forest restoration strategies are selected based on existing site conditions and known land-use history. Some sites may only require passive restoration (Assisted Natural Regeneration), but in many cases, active restoration methods such as Framework Species Method and Maximal Species Diversity Method are needed (Elliot *et al.*, 2013).

Species planted are carefully chosen, taking into consideration the habitat type and specific location they are planted in. As far as possible, the selected species occur naturally in that locality or match the habitat and profile of those naturally occurring in the surrounding nature reserves. Many of the trees and shrubs planted are also propagated from native germplasm from our forests. The

Native Plant Centre supplies 1–3 metre tall saplings grown from seeds collected from our forests, some of which were collected in bulk during masting events. Many of the species propagated by the Native Plant Centre are endangered, such as Banjutan (*Hopea ferruginea*) and Singapore Kopsia (*Kopsia singapurensis*) which are included under NParks' Species Recovery Programme. These endangered species are planted under FRAP in our bid to not only restore the forests but also ensure the long-term survival of these species.

Assisted Natural Regeneration

This method is suitable in areas where seed sources are available nearby and dispersal is not limited, and natural regeneration is already underway. No tree planting is conducted under this method. Instead, weeds like the fast-growing climbers such as the Zanzibar Yam (*Dioscorea sansibarensis*) and Mile-a-Minute (*Mikania micrantha*), and the aggressive ground-covering fern Resam (*Dicranopteris linearis*) that suppress the natural regeneration and succession of native species are removed. Non-native trees that compete with our native tree species are also removed, such as Rubber, Albizia, and African Tulip. The removal of exotic trees is done sensitively and phased over time so as not to adversely affect the habitats provided by some of these species.

Framework Species Method

A framework of light-tolerant, fast-growing, nitrogen-fixing, and fruit-bearing species are introduced, typically early to mid-successional species. By fixing nitrogen in the soil and attracting pollinators and seed dispersers, these species help improve the soil condition and enable more native species to be naturally dispersed from the nature reserves into the regenerating forests. Having fast growth rates and spreading crowns, framework species also allow canopy cover to be established and, hence, weeds to be shaded out quickly in restored sites. This method is often used in areas which have a low density of natural recruitment, but which are relatively close to available seed sources and experienced low to intermediate disturbance in the past. Examples of framework species include nitrogen-fixing trees such as Petai (*Parkia speciosa*) and the Greater Grasshopper Tree (*Archidendron clyperia*), fruit-bearing trees such as the Common Sterculia (*Sterculia parviflora*) and Kumpang (*Horsfieldia polyspherula*), and pollinator-attracting trees such as the Pulai Penipu Paya (*Alstonia angustifolia*).

Maximal Species Diversity Method

This technique involves the planting of a wide range of species, mainly later successional species that are not easily dispersed or are rare in occurrence. This may involve multiple plantings to first plant earlier successional species before introducing species from later successional stages, or may involve the one-off planting of climax forest species in sites with canopy cover already established. This method is chosen for areas which are more remote from the nearest seed source, and have undergone intense degradation or had a long history of disturbance. Some examples of primary rainforest climax species are Dipterocarps (*Shorea* spp., *Hopea* spp., *Dipterocarpus* spp.) and Kempas (*Koompassia malaccensis*).

Community involvement

Community involvement also constitutes a key thrust of FRAP. Stakeholders such as the Friends of the Parks communities, NParks volunteers, schools, corporate organisations, and other members of the community have been contributing to the restoration of our forests by planting trees, collecting seeds and saplings from our forests, propagating them in our community nurseries, conducting invasive species management, and even carrying out research and monitoring of our forest restoration plots.

In 2019, around 2,400 volunteers from over 60 schools and organisations participated in 80 forest restoration activities conducted under the Forest Restoration Action Plan. For instance, about 100 volunteers from Bukit Timah Community Club, WWF Singapore, Kindred, Friends of Bukit Timah Forest, and other community organisations came together to weed *Dioscorea sansibarensis* at the Rifle Range Nature Park in September 2019 (Fig. 1).

Figs. 1. (A) NParks staff briefing the volunteers. (B) Participants, including Adviser Sim Ann and Chairman of the Friends of Bukit Timah Forest, Joseph Koh, with their large haul of weeds. (Photo credit: Cheryl Chia)

Case studies

Thomson Nature Park

Thomson Nature Park is a 50-hectare buffer park bordering the eastern side of the Central Catchment Nature Reserve. As the site of a former Hainan Village, Thomson Nature Park is also rich in cultural heritage. After the village was vacated in the late 1980s, remnant vegetation reclaimed the abandoned land, including fig trees and cash crops such as rambutan, jackfruit, durian and starfruit, and have since served as important food sources for the forest inhabitants there. Over time, the secondary forest at Thomson Nature Park has regenerated, facilitated by its proximity to the Central Catchment Nature Reserve.

Unsurprisingly, Thomson Nature Park is home to a rich diversity of fauna, including many rare and locally endangered animals such as the Malayan Porcupine (*Hystrix brachyura*), Sunda Pangolin (*Manis javanica*), Straw-headed Bulbul (*Pycnonotus zeylanicus*), and Blue-rumped Parrot (*Psittinus cyanurus*). The freshwater streams in the nature park also provide habitat for a range of native aquatic species including the Malayan Box Terrapin (*Cuona amboinensis*). In particular, Thomson Nature Park serves as a key conservation site for the critically endangered Raffles' Banded Langur (*Presbytis femoralis femoralis*).

To further assist the recovery of forest structure and composition, as well as improve the rainforest habitat for these native animals, NParks has been carrying out sensitive habitat enhancement since 2016. Exotic plant species are gradually being removed, and many fruit-bearing species are being planted under the Framework Species Method to strengthen the network of dispersal from seed sources in the nature reserve to the nature park. As of April 2023, 1,579 trees and more than 2,700 shrubs from nearly 200 species were planted in partnership with the community.

In November 2019, nearly 200 students from the Jane Goodall Institute (Singapore) (JGIS) Roots & Shoots programme planted 80 trees along the Ruins and Figs Trail, thereby adopting a forest restoration plot and launching a new programme called 'Plant for Hope' (Fig. 2A). The students have since been returning to the plot to carry out invasive species management and monitor the survival and growth rates of the planted trees (Fig. 2B & 2C). In October 2020, a second round of planting was conducted to further enhance the site.

Figs. 2. (A) Dr Jane Goodall with NParks staff after the launch of the Roots & Shoots' "Plant for Hope" programme on 27 November 2019. (B) Students from the Roots & Shoots schools plot and measure all the saplings planted and any other naturally introduced saplings in the plot. (C) JGIS volunteers maintain the plot by weeding Mile-a-Minute and grasses. (Photo credit: Tan Beng Chiak)

Habitat restoration efforts at Thomson Nature Park encompass the following strategies:

- Removal of invasive species followed by replanting – Oil palms, rubber trees, and other non-native plant species are removed in phases to make way for native species to be planted.
- Planting of Raffles' Banded Langur food plants – From January 2019 to April 2023, more than 800 trees comprising nearly 40 species were planted to increase habitat resources for the Raffles' Banded Langur.
- Planting of keystone species – Keystone species such as figs, which produce fruit all year round, are planted to provide a constant supply of food for animals in the nature park.
- Stream restoration – Ferns and riverine plants are planted by stream banks to prevent erosion and to improve the health of the stream for aquatic species.
- Planting to enhance ecological connectivity – Trees with spreading canopies are planted along the edge of the nature park to improve connectivity for arboreal animals which regularly cross between the nature reserve and nature park in search for food and mates.

The 3-kilometre-long Old Upper Thomson Road separates the Central Catchment Nature Reserve from Thomson Nature Park as well as forest patches in Upper Thomson, Lentor, and Tagore, making the road a focal stretch for ecological connectivity to be enhanced. To facilitate the movement of the Raffles' Banded Langur and other arboreal animals, rope bridges have been installed along the road at locations where the langurs have been observed to habitually cross. Culverts are also being maintained to promote the crossing of terrestrial animals. By increasing connectivity for arboreal and terrestrial mammals that are important seed dispersers, such as the

Long-tailed Macaque (*Macaca fascicularis*), Lesser Mousedeer (*Tragulus kanchil*), and Malayan Colugo (*Galeopterus variegatus*), these efforts are important in aiding the natural regeneration of the forest. A similar approach has been implemented at Rifle Range Nature Park.

Chestnut Nature Park

Previously the site of a kampung, Chestnut Nature Park had part of its forest cleared during the early 1900s to make way for agricultural activities. As the villagers eventually moved out and the kampungs were demolished, pockets of open space were left to be taken over by nature once again. Fast-growing exotic species such as Albizia and African Tulip soon started to dominate, along with other non-native fruit trees and oil palms.

Forest restoration efforts at Chestnut Nature Park have been concentrated on sensitively removing the non-native species in phases to ensure that habitat resources are maintained, while carrying out replanting with native trees to aid regeneration of the young secondary forest. A combination of the Framework Species Method and Maximal Species Diversity Method is used, due to the variation in site conditions of the different plots. In open plots without pre-existing canopy cover, fast-growing native tree species that can tolerate full sun conditions, such as Jelutong (*Dyera costulata*), are typically chosen to enable quick establishment of the canopy cover. Canopy closure deters the growth of sunlight-loving weeds which can smother native trees and hinder their growth. Fruit-bearing trees such Santol (*Sandoricum koetjape*), Salam (*Syzygium polyanthum*), and Rambai (*Baccaurea motleyana*) are chosen to attract frugivorous birds and bats, which assist natural regeneration by bringing in other seeds from nearby seed sources. Keystone species which fruit all year round, such as various species of fig trees, are planted as well. In sites where non-native trees have been selectively retained, mid- to late-successional species that require moderate light conditions and humidity are grown under the shade of the non-native trees. Examples of such species are Sepetir (*Sindora wallichii*), Gaharu (*Aquilaria malaccensis*), Tempinis (*Streblus elongatus*), and nitrogen-fixing legumes such as Kempas (*Koompassia malaccensis*). Enrichment planting of these species is also carried out in the understorey layer of less diverse secondary forest sites, to help overcome the limited natural dispersal range of seeds from primary forest patches.

From January 2019 to April 2023, more than 2,759 native trees from 70 species were planted in Chestnut Nature Park. NParks has been working closely with the Friends of Chestnut Nature Park and the National University of Singapore (NUS) Ridge View Residential College (RVRC) on forest restoration programmes, including tree planting, weeding, and growth monitoring at Chestnut Nature Park (Fig. 3 & 4).

Figs. 3. (Top left and bottom left) The Chestnut Point restoration site in August 2018 before the commencement of forest restoration efforts. (Top right and bottom right) The Chestnut Point restoration site in February 2020, after 101 trees were planted in September 2018. (Photo credit: RVRC (bottom left and right))

Figs. 4. (A) Dr Chua Siew Chin and her RVRC students after a weeding session at Chestnut Nature Park to remove non-native climbers such as *Mikania micrantha*. (B) RVRC students after a tree planting event at Chestnut Nature Park. (Photo credit: RVRC)

Rail Corridor

Since 2018, the central and southern stretches of the Rail Corridor have been rewilded and planted up with more than 4,931 native trees. Similar to the restoration undertaken at Chestnut Nature Park, a phased approach is used to progressively remove exotic species such as Albizia and African Tulip along the Rail Corridor, and replace them with native tree species. Most of the trees planted initially were fast-growing species in order to quickly provide shade, but increasingly, a greater number of slower-growing forest species and native fruit trees are being planted to provide a lush green belt for biodiversity to thrive. Following the Maximal Species Diversity Method, a wide range of mid- to late-successional species are chosen, including the Shore Laurel (*Neolitsea cassia*), Derum (*Cratoxylum maingayi*), Cheng Tng Tree (*Scaphium macropodum*), Keruing Belimbing (*Dipterocarpus grandiflorus*), Small-leaved Oil-fruit (*Elaeocarpus mastersii*) (Fig. 5), and the critically endangered Cengal Pasir (*Hopea sangal*) and Singapore Kopsia (*Kopsia singapurensis*).

Figs. 5. The Small-leaved Oil-fruit (*Elaeocarpus mastersii*) is a medium-sized tree that grows in primary and secondary lowland to montane forests. It occurs locally in the Bukit Timah and Central Catchment Nature Reserves. As its fruits and seeds are eaten and dispersed by birds, it is commonly planted to encourage natural recruitment through dispersal by birds. (A) Foliage of *Elaeocarpus mastersii*. (B) The greyish-blue, round-oval fruits of *Elaeocarpus mastersii*. (Photo credit: Ang Wee Foong)

Due to the heterogeneity in habitat type and landscaping narrative along the green corridor, different sections of the Rail Corridor will feature different planting palettes. The planting plan for the central stretch will mainly focus on forest species. Moving further north, the composition of species planted will gradually shift from forest species to back mangrove species, while in the south, the planting palette will incorporate native fruit trees and economically important species.

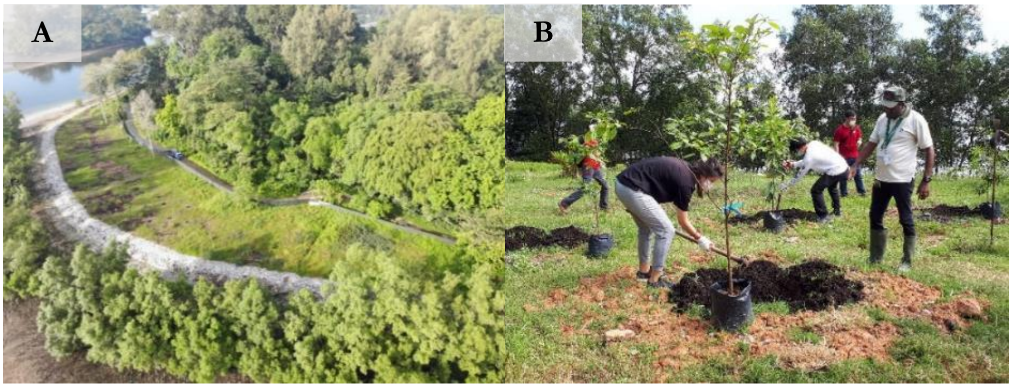
Traversing Singapore from north to south and linking several estates, the Rail Corridor also has a special role to play in connecting communities. In October 2018, around 200 volunteers came together to enhance a stream along Rail Corridor (Central) near Rail Mall. This stream used to be a concrete drain that served the railway tracks, but its walls had since collapsed. The volunteers planted a variety of species to help filter and clarify the water, making it more conducive for the aquatic species residing in it. *Magnolia singapurensis,* an endangered native swamp species, was also planted there as part of NParks' species recovery efforts. Since then, more than 55,000 native trees and shrubs have been planted by more than 930 members of the community as part of habitat enhancement efforts along the Rail Corridor (Fig. 6). NParks will continue to actively engage communities living along Rail Corridor, as well as the Friends of the Rail Corridor, to involve them in further intensifying the greenery of, and enhancing habitats along, the Rail Corridor.

Figs. 6. (A) A BES (Bachelor of Environmental Studies) Drongo member carrying out stream restoration planting at Rail Corridor (Central) in October 2018. (B) Planting of the endangered *Magnolia singapurensis* by Minister Desmond Lee, Adviser Christopher de Souza, Adviser Sim Ann, former Adviser Liang Eng Hwa, then NParks CEO Kenneth Er, and URA CEO Lim Eng Hwee. (Photo credit: (A) Jeanne Tan)

Kranji Coastal Nature Park

Kranji Coastal Nature Park, part of the Sungei Buloh Nature Park Network, contains a variety of habitats – secondary forest, coastal beach, as well as mangrove. Over the years, however, the coast has been affected by severe erosion, leading to the loss of plants and intertidal habitats. In addition, the damming of the river has reduced sedimentation, impeding natural recovery from occurring.

To prevent further erosion and restore the habitats, NParks undertook the installation of a rock revetment beyond the mangroves in 2019, following which regrading works and soil backfilling were also done (Fig. 7A). This regraded area was incorporated within NParks' coastal forest restoration plan in Kranji Coastal Nature Park, a plan that seeks to restore the secondary forest, coastal forest, and mangrove forest habitats. The restoration approach for this site entails the planting of suitable framework species, such as nitrogen-fixing legumes to improve the disturbed soil, and fruit-bearing trees to attract dispersers like birds to bring in species from the adjacent forests. Specially selected coastal and back mangrove species such as Nyatoh Puteh (*Palaquium obovatum*), Sparrow's Mango (*Buchanania arborescens*), Pelir Musang (*Fagraea auriculata*), and Sepetir (*Sindora wallichii*) are also planted. Additionally, the mangrove forests are now naturally recruiting on their own due to the rock revetment slowing down coastal erosion. Over time, the restored mangroves will serve to protect the area from coastal erosion – a form of nature-based solution. Since June 2020, planting efforts in Kranji Coastal Nature Park have intensified (Fig. 7A), and a wide spectrum of the community has been roped in to join in the efforts, including the Friends of Sungei Buloh Wetland Reserve, nature groups, and educational institutions like NUS and Singapore University of Social Sciences (Fig. 7B).



Figs. 7. (A) Aerial view of the restoration site situated between the rock revetment and the existing secondary forest, taken before forest restoration efforts began at this site. (B) Volunteers from NUS planting at the restoration site.

Monitoring forest restoration efforts

On top of the ongoing forest restoration efforts, monitoring and research form an important component of FRAP, in order that the methods used may be continuously finetuned and improved upon where necessary, and the capacities and best practices in forest restoration be developed. To this end, NParks has been working alongside researchers and members of the community.

One such research project, led by Dr Chong Kwek Yan (then from NUS) and his students, Lorraine Tan (2016–2017) and Tan Boxin (2019–2020), investigated the effects of understorey weeding in Singapore's secondary forests. Through the setting up of experimental plots at Labrador Nature Reserve, Bukit Batok Nature Park, and Windsor Nature Park, it was found that weeding can reduce native seedling mortality and increase native seedling recruitment, but periodic weeding and long-term monitoring are required for these effects to be discernible. Monitoring will be continued at all three sites and re-weeding will be done in the two nature parks. Belowground-aboveground linkages that may help explain the differences in weed re-invasion success between plots, will also be further explored, which will help shed light on the mechanisms through which invasive species affect native seedling survival and recruitment. This project has important implications for the way we understand and conduct invasive species management.

Past land use can greatly influence the trajectory of forest recovery – different land-use histories may hence necessitate different restoration strategies to accelerate the forest regeneration process. Another project, conducted by Dr Chua Siew Chin and her NUS RVRC students, leverages the varied land-use history and vegetation types across Chestnut Nature Park to test different restoration strategies (Fig. 8). The team first assesses the existing site conditions of a plot, including the vegetation cover, plant diversity, and soil quality. They then implement the appropriate site preparation work and planting strategy, and subsequently follow up with regular monitoring of the survival and growth rates of the planted trees. Over two years of monitoring, they have found that under specific light and soil conditions, certain planted species have higher survival and growth rates than others, and that mulch application leads to marginally higher growth rates at sites with degraded soil. They are presently experimenting with filling the planting holes with improved soil mixture at degraded sites. The team has also determined that a higher planting density of 1 to 1.5 metres' distance between trees, rather than 2 to 2.5 metres, is more effective at achieving canopy closure after one year. RVRC's monitoring efforts will continue to help inform the best practices for forest restoration through the iterative process of adaptive management.

Fig. 8. Dr Chua Siew Chin and her RVRC students conducting research and monitoring on the survival and growth rates of tree species in the Chestnut Nature Park restoration plots. (Photo credit: RVRC)

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CHAPTER 5

Rifle Range Nature Park: Restoration of Two Ecosystems

Sharon Chan, Sunia Teo, Cheryl Chia & Kee Wen Yu

Rifle Range Nature Park (RRNP) is a 66-hectare nature park located at the southern end of Bukit Timah Nature Reserve (Fig. 1). The park serves as an important buffer to the Bukit Timah Hill, Singapore's highest hill, which remains one of the few areas of primary rainforest and the home to around 40% of Singapore's native flora and fauna in the country.

As a buffer park, RRNP provides not only habitat for native fauna but also food sources for them to survive on. Habitat restoration is pivotal for the development of this park, which is part of a holistic approach to strengthen biodiversity conservation in Singapore's nature reserves while providing interesting alternative venues for the public to enjoy nature-related activities in a highly urbanised city-state.

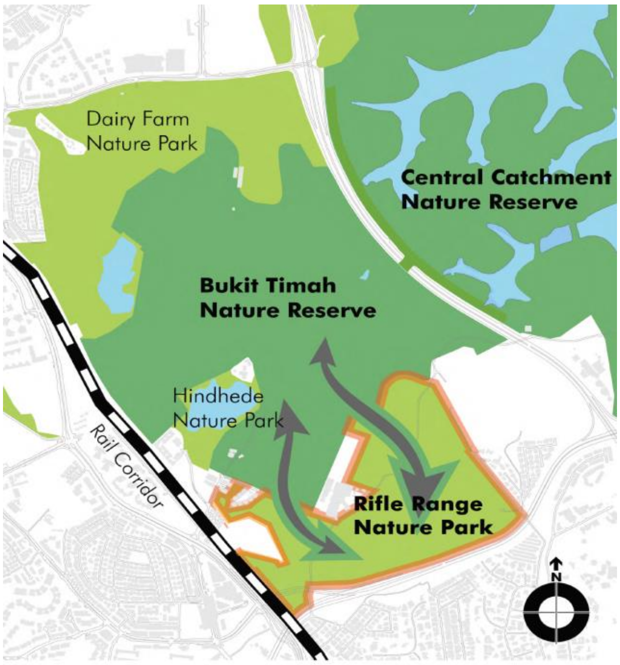

Fig. 1. Map showing the link between Bukit Timah Nature Reserve and Rifle Range Nature Park.

The key challenges for this nature-sensitive project were to: 1) find a balance between the development of recreation uses and conservation of biodiversity through habitat restoration and 2) integrate a data-driven, science-based approach at all stages of the park development process.

Guiding principles

A clear goal of restoration

From the early stages of the park's planning, the goal of restoring its natural historical ecosystem was established as central to the project. Historically, the site was a granite hill with secondary forests, villages, and quarrying activities from the 1950s to the 1980s. By the 1990s, quarrying activities stopped, and the quarry was backfilled. Villagers were also resettled due to the quarry's closure. With decades of undisturbed period and minimal human intervention, some species of flora and fauna from the Bukit Timah Nature Reserve have re-established themselves in the Nature Park. The clear goal of restoration served as an important guide in the making of the nature park so that decisions to protect ecological habitats were prioritised over recreational needs.

Data-driven design and planning

The planning and design of RRNP were based on scientific data. Before designing of the park in the existing forest commenced, areas of high biodiversity and significant large trees with high conservation value needed to be identified and protected. Hence, a nine-month-long biodiversity study was commissioned to document and map out the floristic and fauna diversity. The study entailed line-transect surveys of over 10 kilometres conducted by systematically walking the site and recording sightings for flora and fauna, plot sampling, and deployment of over 110 camera traps strategically placed within the site. The camera traps were programmed to be active 24 hours per day at high sensitivity to collect video footage when triggered by movement or changes in temperature. The detailed baseline study at the planning stage was fundamental for the subsequent design and implementation of the park.

Site history

The land at RRNP had been left to regenerate for approximately 30 years. The majority of the site was covered by young secondary forest and scrubland appearing to be degraded due to the lack of large, tall trees and a closed-canopy layer, the widespread presence of exotic and weedy vegetation, the open understorey, and large areas of muddy soil. Scattered throughout the site were vestiges of kampung settlements, in the form of cultivated vegetation, concrete foundations, roads and paths, pottery and other curios, and lastly, trash.

One of the biggest disturbances to the site was Sin Seng Quarry. Shut down and backfilled in the 1990s, the site of the quarry remained barren until 2003. Scrubs and weeds infiltrated the area. The quarry site was largely covered by ferns and pitcher plants, both indicators of high light penetration and poor soil conditions.

Two streams flow through RRNP. The source for one stream is from Bukit Timah Nature Reserve. The other stream, which begins as a pond adjacent to Murnane Reservoir and flows south to the Pan-Island Expressway, also has a tributary at its southern end which stretches to Jalan Kampong Chantek.

Baseline information

Based on the vegetation mapping carried out from March 2017 to March 2018, RRNP comprised largely secondary forest from abandoned plantations and several kampung (64%), followed by scrubland/herbaceous vegetation (24%), managed vegetation (4.4%), native-dominated low secondary forest (4.3%), waste-woodlands (Fig. 2) (1.7%), stream vegetation (0.7%), swampland (0.2%) and pond vegetation (Yee *et al.*, 2016). The flora survey recorded a total of 401 species of vascular plants from 106 families of which there were 184 species of trees, 127 species of shrubs/herbs and 90 species of climbers (unpublished report: Baseline survey of RRNP, 2018, carried out by Camphora Pte. Ltd.).

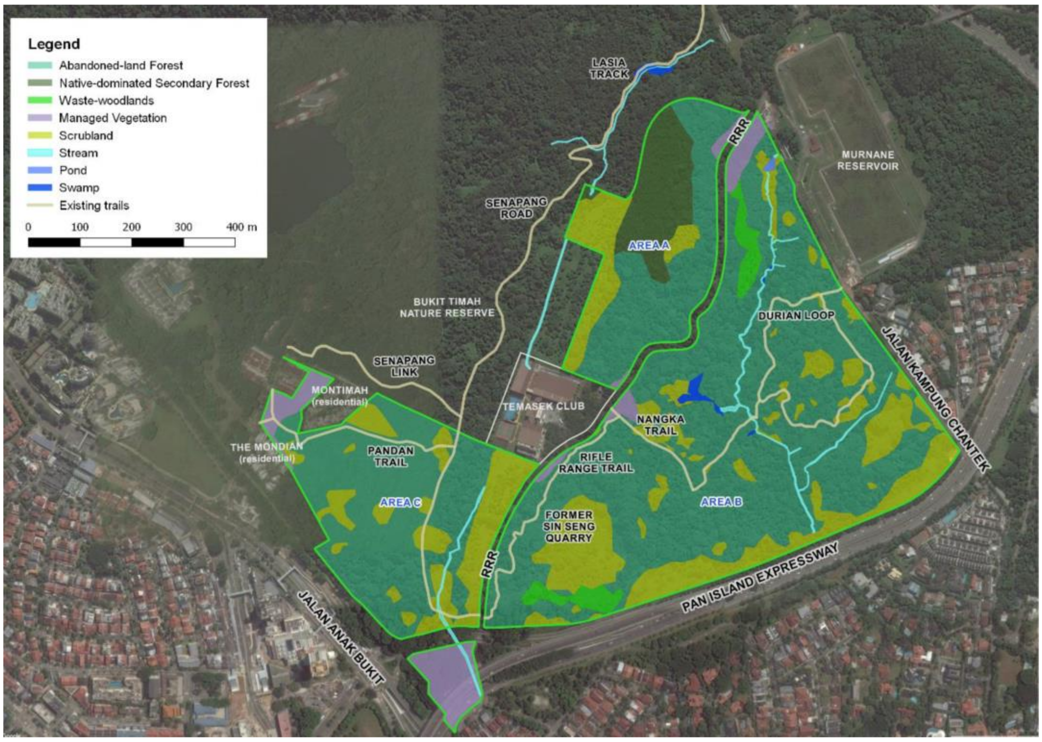

Fig. 2. Map illustrating the various vegetation types identified at Rifle Range Nature Park. (Image credit: Camphora Pte. Ltd.)

The fauna transect surveys and live-trapping recorded 288 species, consisting of 36 odonate, 87 butterfly, seven fish, four decapod crustacean, 56 herpetofauna, 79 bird, and 19 mammal species including the Sunda Pangolin (*Manis javanica*) and Leopard Cat (*Prionailurus bengalensis*), which are critically endangered locally.

The results of the study guided the restoration of natural habitats, informed the design of the nature park and ensured that the implementation of works was done sensitively and sustainably. The work included several ecological enhancements such as habitat enhancement, implementation of wildlife connectivity features and incorporation of sustainability elements in the park design. Based on the preliminary findings, recommendations focussed on the creation of ecological habitats and connectivity, as well as enhancement of stream and fauna habitats.

Implementing habitat restoration

NParks' Forest Restoration Action Plan (FRAP) was drawn to operationalise the Nature Conservation Masterplan. It was formulated to chart the restoration initiatives that would be undertaken over 10 years to regenerate the secondary forests in the buffer parks surrounding the Bukit Timah and Central Catchment Nature Reserves, as well as disturbed patches within the Reserves.

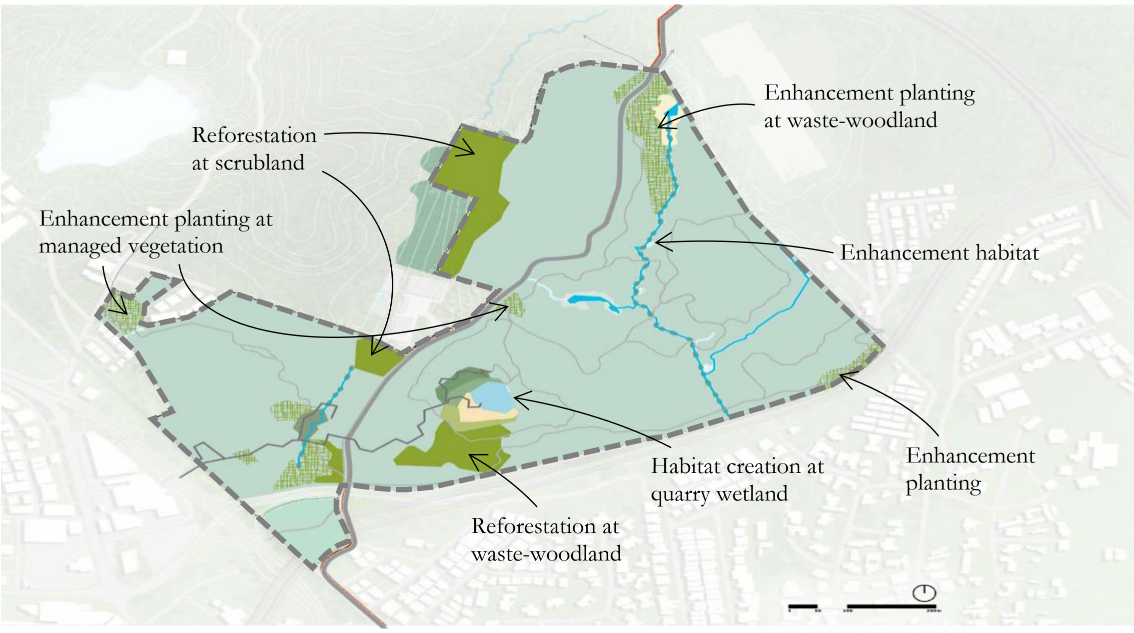

Fig. 3. Map showing targeted habitat restoration methods. (Image credit: Henning Larsen Pte. Ltd.)

NParks applies a combination of three forest regeneration techniques to assist the forests to evolve into a mature forest landscape over time. The habitat restoration sites in RRNP identified jointly by NParks, Camphora Pte. Ltd., and Henning Larson Pte. Ltd. are shown in Fig. 3.

General principles used

1) Maximal Species Diversity

Dominant primary rainforest species that may be limited by dispersal or are rare in occurrence, were introduced (Annex I). The seedlings of such species are adapted to shade conditions and depend on the canopy of the secondary forests in the nature parks to establish themselves.

2) Framework Species Method

A framework of native leguminous tree species and fruit-bearing tree and shrub species is introduced as indicated below:

These species (Annex II) fix nitrogen in the soil and attract animals and insects which assist with seed dispersal and pollination. Over time, the soil condition improves and enables more native species to be naturally dispersed into the regenerating forests from the Nature Reserves. This technique is used to restore main areas of scrubland.

3) Assisted Natural Regeneration

Exotic weeds (e.g., *Dioscorea sansibarensis*, *Falcataria moluccana*, *Spathodea campanulata*, and *Leucaena leucocephala*) that compete with native tree species in forest regeneration are removed.

This is sensitively implemented over time to avoid impacting habitats provided by some of these species. To restore smaller areas of scrubland, this method is most appropriately carried out by marking and protecting the native seedlings.

Key habitats restored

Forest habitat

Kampung vegetation was retained as it served as the key framework providing food source and home to the resident fauna recorded here. The maximal species diversity was applied with the planting of native species saplings. Most of the large trees with girth size greater than 1.5 metres were kept. These large trees included *Durio zibethinus*, *Nephelium lappaceum*, *Ficus vasculosus*, *Palaquim gutta*, and *Xanthophyllum obscurum*.

Native species planted included legumes, such as Petai (*Parkia speciosa*), fruit-bearing trees such as the Common Sterculia (*Sterculia parviflora*) and the Kumpang (*Horsfieldia polyspherula*), and pollinator-attracting trees such as the Pulai Penipu Paya (*Alstonia angustifolia*). This would ensure species recovery by increasing the amount of native flora for native wildlife in the area.

In large open areas, framework species comprised a mixture of emergent trees, canopy trees and understory trees and shrubs. Fast growing species that would shade out weeds and fruit-bearing trees were included to attract seed dispersers. This involved the planting of nitrogen-fixing native species *Koompassia malaccensis* and *Parkia speciosa* that would naturally improve the soil condition, as well as attract dispersers and pollinators. Dominant primary rainforest species, which were limited by dispersal or were rare in occurrence, were also introduced, e.g., *Dipterocarpus kunstleri*, *Dipterocarpus cornutus*, *Dipterocarpus costulatus*, etc. These were selected for this site as they were found in the nature reserves.

Figs. 4. (A) A Reforestation Corridor taken in April 2021 just after planting; (B) Reforestation Corridor 18 months later, October 2022.

As in all open areas and forest edges, the weeds and climbers established rapidly and smothered these plants, such as *Dioscorea sansibarensis*, which was difficult to eradicate. Regular removal of this climber on these newly planted sites was carried out to prevent it from spreading and inhibiting the growth of the saplings.

This helped the forest to establish and enhance the nature park's biodiversity and ecological connectivity, as well as strengthen the resilience of the forests to climate change. Fig. 4A and 4B show how the site had changed over an 18-month period as a result of habitat restoration.

Wetlands habitat

The former Sin Seng Quarry, once one of Singapore's deepest quarries at 55 metres deep, had been filled with soil during the late 1990s and over the years, it had become an open scrubland where exotic species were seen to be colonising. As part of the habitat restoration of RRNP, this was enhanced as a freshwater habitat based on the schematic approach designed jointly by NParks, Camphora Pte. Ltd., and Henning Larson Pte. Ltd. shown in Fig. 5.

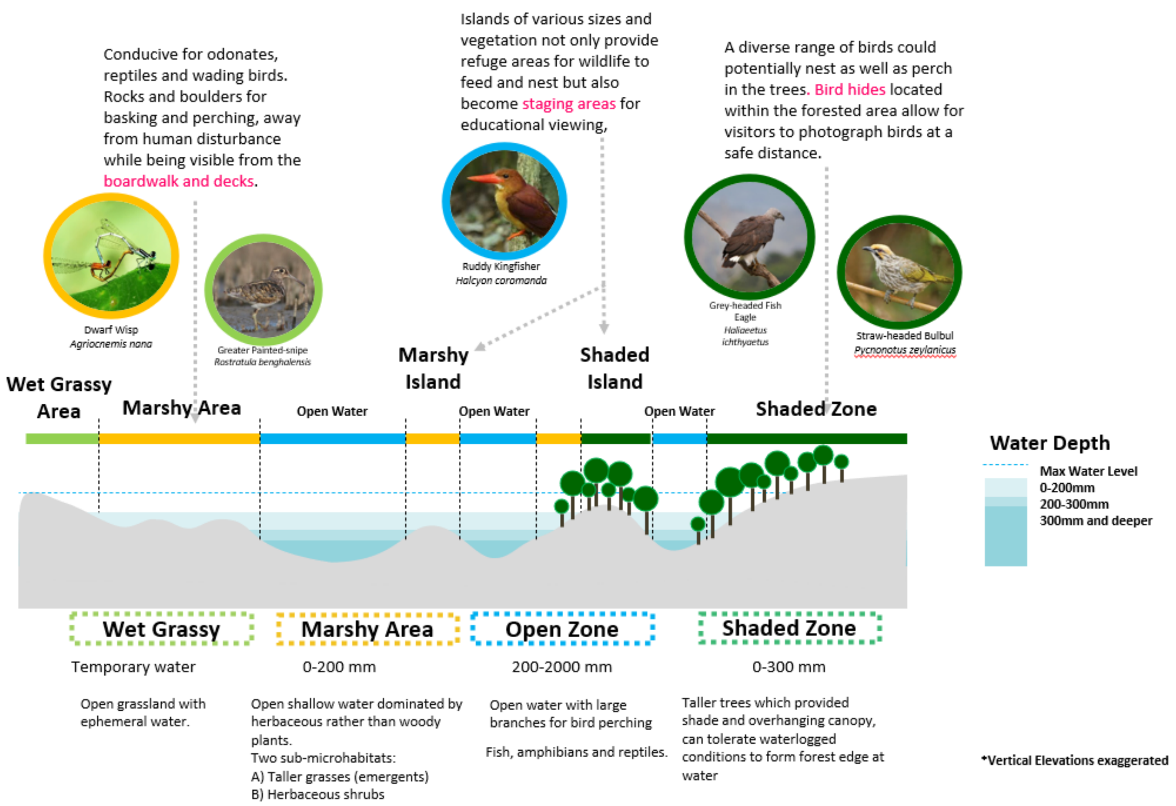

Fig. 5. A schematic drawing on the restoration of a wetland habitat. (Image credit: Henning Larsen Pte. Ltd.)

The restoration of the freshwater wetland ecosystem improved the water quality and provided habitats for wetland animals and migratory birds such as the Blue Percher (*Diplacodes trivialis*), Yellow Bittern (*Ixobrychus sinensis*) and Malayan Water Monitor (*Varanus salvator*) (Fig. 6).

Fig. 6. Freshwater habitat at the Quarry Wetland.

At the open water area, emergent, floating, and submerged plants were introduced. Mainly small clusters of Water Snowflake (*Nymphoides indica*) and dense hedges of *Lepironia articulata* were planted.

Closer to the water edge, species including Leather Fern (*Acrostichum aureum*), *Alocasia longiloba*, aquatic ginger (*Alpinia aquatica*), and Chinese Water Chestnut (*Eleocharis dulcis*) were planted.

The banks, comprising largely of marshy and wet grasslands, were dominated by *Dillenia suffruticosa*. These areas were enhanced with the planting of water-tolerant shrubs, herbs, and climbers including Slender Pitcher Plant (*Nepenthes gracilis*), Finlayson's Bromheadia (*Bromheadia finlaysoniana*) and Bamboo Orchid (*Arundina graminifolia*), *Spathoglottis plicata*, *Alocasia longiloba*, Love Grass (*Eragrostis unioloides*), and Sword Fern (*Nephrolepis biserrata*), Singapore Rhododendron (*Melastoma malabathricum*) and Climbing Fern (*Stenochlaena palustris*).

At the shaded area, existing trees were kept, and enhancement planting were carried out. Water-tolerant trees species were planted to provide canopy cover. These include Mempat (*Cratoxylum formosum* and *Cratoxylum cochinchinense*), Marsh Pulai (*Alstonia spatulata* and *Alstonia pneumatophora*), Stilted Simpoh (*Dillenia recticulata*), Lipstick Palm (*Cyrtostachys renda*), and Tree Fern (*Alsophila latebrosa*).

Community involvement

Initiating nature-sensitive programmatic planning for RRNP is important to engage, educate, and involve communities to help with nature conservation. One such programme is the Invasive Species Management (ISM), which involves residents and the nature community to help weed out invasive alien species that pose an ever-increasing threat if left unmanaged. This would facilitate habitat restoration.

During fruiting seasons, especially masting, seeds are collected and propagated in the Community Nursery built at the park. This ensures that the native gene stocks are conserved for replenishing the plant populations at RRNP. Volunteers from the community can help with the propagation of native plants that are used in restoring and enhancing the different ecosystems found in RRNP.

The RRNP Community Nursery will specialise in the propagation of native pioneer and secondary forest species to be planted in RRNP under FRAP. Nature parks act as ecological buffers and provide complementary habitats for flora and fauna in the nature reserves. As part of NParks' efforts to expand our natural capital, native tree species that support local fauna will be propagated and planted out to enhance the habitats in the regenerating forests of various nature parks. Annex III lists more comprehensively the flora species planting palette that has been carefully selected for planting within RRNP for general habitat restoration.

Conclusions

RRNP is one of the efforts to operationalise FRAP that is integral to NParks' habitat enhancement and restoration programme. It is one of the key thrusts of NParks' Nature Conservation Masterplan that was launched in 2015 to chart Singapore's plans for biodiversity conservation.

For nature sensitive development, there is a delicate balance between the development of recreation uses and conservation of biodiversity. Besides habitat enhancement, the design features of RRNP are closely integrated with biophilic design elements to encourage people's well-being and human-nature interactions. The design of the trails is also user-centric offering an inclusive and unique visitor experience of harmony with nature. One of the popular trails is the trail leading to the Wetlands Quarry and the Colugo Deck, inspired by the silhouette of a Sunda Colugo.

Community stewardship is key to protecting our native flora and fauna. Through guided walks, NParks reaches out to the public to learn more about our native wildlife. By participating in ISM and the plant propagation programme, people can gain a better understanding of the efforts in conservation.

Since its launch on 12 November 2022, RRNP has shown that habitat restoration reaps multiple benefits, with faunal records increasing to 300. Habitat restoration will only work out well when the site is protected and properly managed sustainably and ecologically on a long-term basis with compatible development carried out sensitively in its vicinity (Fig. 7). Wildlife has benefitted from the restoration as faunal records have increased to 300.

Restoration is futile without reasonable assurance that the project site will be protected and properly managed sustainably and ecologically on a long-term basis with compatible development carried out sensitively in its vicinity.

Fig. 7. View of RRNP from the top of Colugo Trail.

References

Yee ATK, Chong KY, Neo L & Tan HTW (2016) Updating the classification system for the secondary forests of Singapore. Raffles Bulletin of Zoology Supplement, 32: 11–21.

Annex I: Dominant primary rainforest species which might be limited by dispersal or are rare in occurrence

Aquilaria malaccensis
Dialium indum
Dillenia grandifolia
Dillenia reticulata
Dipterocarpus cornutus
Dipterocarpus costulata
Dipterocarpus grandiflorus
Dipterocarpus kunstleri
Dyera costulata
Hopea ferruginea
Hopea griffithii
Hopea mengarawan
Hopea sangal
Intsia palembanica
Knema curtisii
Koompassia malaccensis
Parishia insignis
Parkia speciosa
Pentace triptera
Rhopaloblaste singaporensis
Scaphium macropodum
Shorea curtisii
Shorea leprosula
Shorea macroptera
Trigonaches acuta
Vatica odorata
Xanthophyllum ellipticum

Annex II: Leguminosae family, with nitrogen fixing properties

Archidendron bubalinum (*Albizzia spendens*)
Archidendron clypearia
Archidendron jiringa
Cynometra ramiflora
Dialium indum
Intsia palembanica
Koompassia malaccensis
Parkia speciosa
Sindora wallichii

Annex III: Comprehensive planting palette used for RRNP

Trees and palms

Alsophila latebrosa
Alstonia spatulata
Aporosa penangensis
Aquilaria malaccensis
Archidendron bubalinum (*Albizzia spendens*)
Archidendron clypearia
Archidendron jiringa
Ardisia elliptica
Artocarpus elasticus
Baccauarea brevipes
Baccauarea motleyana
Barringtonia racemosa
Barringtonia reticulata
Bouea macrophylla
Bouea oppositifolia
Buchanania arborescens
Calophyllum soulattri
Campnosperma auriculata
Carallia brachiata
Caryota mitis
Cleistanthus malaccensis
Cratoxylum cochinchinense
Cratoxylum formosum
Cratoxylum maingayi
Cynometra ramiflora
Cyrtophyllum fragrans
Cyrtostachys renda
Dialium indum
Dillenia excelsa
Dillenia grandifolia
Dillenia indica
Dillenia reticulata
Dillenia suffruticosa
Diospyros buxifolia
Diospyros lanceifolia
Dipterocarpus cornutus
Dipterocarpus costulata
Dipterocarpus grandiflorus
Dipterocarpus kunstleri
Dracaena maingayi
Dyera costulata
Elaeocarpus mastersii
Elaeocarpus petiolatus
Eleiodoxa conferta
Eurycoma longifolia
Ficus consociata
Ficus macrocarpa
Ficus microcarpa
Ficus variegata
Flacourtia rukam
Garcinia atroviridis
Garcinia hombroniana
Garcinia parviflora
Garcinia prainiana
Gardenia tubifera
Gnetum gnemon
Gynotroches axillaris
Heritiera simplicifolia

Trees and palms *(Cont'd)*

Hopea ferruginea
Hopea griffithii
Hopea mengarawan
Hopea sangal
Horsfieldia irya
Horsfieldia polyspherula
Horsfieldia superba
Iguanura wallichiana
Ilex cymosa
Intsia palembanica
Knema curtisii
Koompassia malaccensis
Korthalsia sp.
Leea angulata
Lepisanthes rubiginosa
Licuala ferruginea
Litsea elliptica
Mangifera caesia
Mangifera foetida
Maranthes corymbosa
Memecylon caeruleum
Memecylon pauciflorum
Neolitsea cassia / N. zeylanicum
Ochanostachys amentacea
Oncosperma tigilarium
Palaquium gutta
Palaquium obovata
Pandanus atrocarpus
Parishia insignis
Parkia speciosa
Pentace triptera
Phyllanthus emblica
Ploiarium alternifolium
Pometia pinnata
Pouteria obovata
Pteleocarpa lamponga
Radermanchera quadripinnata
Rhopaloblaste singaporensis
Sandoricum koetjape
Scaphium macropodum
Shorea curtisii
Shorea leprosula
Shorea macroptera
Sindora wallichii
Steblus elongatus
Sterculia cordata
Sterculia parviflora
Sterculia rubiginosa
Streblus elongatus
Suregada multiflora
Syzygium borneensis
Syzygium carasiforme
Syzygium glaucum
Syzygium lineatum
Syzygium myrtifolium
Syzygium polyanthum
Syzygium singaporense
Syzygium syzygioides
Syzygium zeylanicum
Tarenna odorata

Trees and palms *(Cont'd)*

Trigonaches acuta
Vatica odorata
Xanthophyllum ellipticum

Shrubs and ground covers

Acrostichum aureum
Agrostistachys borneensis
Alocasia longiloba
Alpinia aquatica
Alpinia conchigera
Angiopteris evecta
Ardisia crenata
Arundina graminifolia
Asplenium longissimum
Asplenium nidus
Blechnopsis orientalis
Blechnum finlaysonianum
Bromheadia finlaysoniana
Cayratia mollisima
Centotheca lappacea
Cheilocostus speciosus
Chonemorpha fragrans
Clerodendrum inerme
Clerodendrum laevifilium
Crinum asiaticum
Cyathula prostata
Cyclosorus polycarpus
Cymbopogon citratus
Cyperus alternifolius
Davalia denticulata
Dianella ensifolia
Donax canniformis
Dracaena porteri
Eleocharis dulcis
Eragrostis unioloides
Ficus apiocarpa
Ficus deltoidea
Ficus recurva
Flacourtia rukam
Flagellaria indica
Freycinetia javanica
Gardenia tubifera
Gomphandra quadrifida
Grammatophyllum speciosum
Hydrocotyle sibthorpioides
Ipomea pes caprae
Ixora congesta
Ixora lobbii
Kopsia singapurensis
Lasia spinosa
Leea indica
Leea rubra
Lepironia articulata
Licuala spinosa
Loeseneriella macrantha
Melanthera biflora
Melastoma malabathricum

Shrubs and ground covers *(Cont'd)*

Memecylon ovatum
Micrechites serphllifolius
Microsorum scolopendria
Molinera capitulata
Molinera latifolia
Mucuna biplicata
Nenga pumila var.polystachya
Nepenthes gracilis
Nephrolepis biserata
Nephrolepsis falcata
Nymphoides indica
Pandanus pygmaeus
Pellionia repens
Phanera semibifida
Phymatosorus scolopendria
Pinaga disticha
Piper sarmentosum
Pityrogramma calomelanos
Poikilospermum sp.
Premna serratifolia
Psychotria maingayi
Pteris semipinnata
Rhodomyrtus tomentosa
Rothmannia macrophylla
Sauropus androgynus
Schismatoglottis calyptrata
Schumannianthus dichotomus
Scindapsus pictus
Selaginella sp.
Selaginella wildenowii
Spathoglottis plicata
Stenochlaena palustris
Tabernaemontana corymbosa
Tarenna fragra
Tectaria singaporiana
Tetracera indica
Thottea grandiflora
Tristellateia australasiae
Vanilla griffithii

CHAPTER 6
Enhancing Habitats in Bidadari

Tan Yit Chuan & Low Bing Wen

Introduction

Bidadari Cemetery was one of the first cemeteries created following the founding of Singapore (Goh, 2002). Under the 1998 URA Masterplan, the cemetery was zoned for development as high-density housing. In 2003, the graves were exhumed and for the next 15 years, the site was left vacant.

Since the 1990s, the area has been well known as a site for nature appreciation. However, it shot to prominence in the early 2000s as a haven for birds, in particular as a stopover site for migratory landbirds. Bidadari's ease of access, coupled with the rise in popularity of nature photography in Singapore, meant that the site became a birdwatching hotspot for at least a decade right up to its current closure for development.

Background information

The core area of interest at Bidadari was the well-wooded area that was once the Muslim Cemetery. This green space of approximately 16 hectares consisted of two hillocks linked by an area of lower ground between them. A stream (canalised and overgrown) ran along the western boundary of the site parallel to Upper Serangoon Road. There was an additional canalised stream that ran from the southwestern to northeastern end of the site along the boundary between the woodland and grassy field.

In 2003, URA exhumed the tombstones in the area but left most of the extant vegetation in the area intact (Fig. 1). By 2013, the area of extant vegetation had recovered to such an extent that it appeared as a small area of secondary forest from the air (Fig. 2).

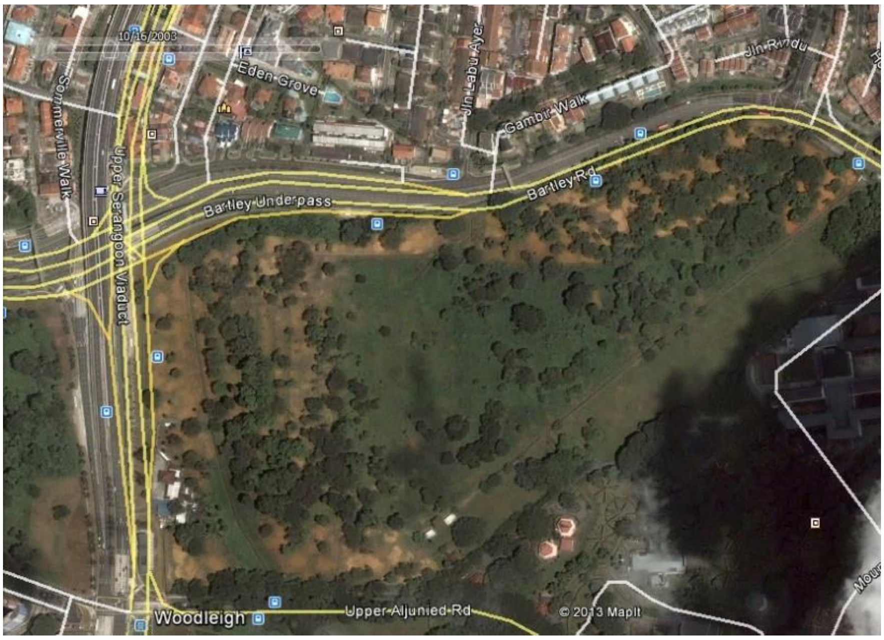

Fig. 1. Aerial view of the former Bidadari Muslim Cemetery just after the graves were exhumed in 2003. (Image credit: Google Earth)

Fig. 2. Aerial view of the former Bidadari Muslim Cemetery in 2012, a decade after the exhumation of the graves. (Image credit: Google Earth)

A preliminary survey of vegetation at the site in 2013, with a focus on trees, recorded 60 species of plants, of which 29 were native to Singapore. Of these 29 species, 15 were trees, seven were epiphytes, five were climbers and two were shrubs. With the exception of several uncommon mistletoe species, none of the native plants were of conservation concern.

The area rose to prominence in 2009, with more people getting into nature photography in Singapore; it was widely considered to be one of the most accessible birdwatching sites in Singapore. Woodleigh MRT is located at the southwest boundary of the site, while the entire region is served by a comprehensive network of buses.

Birds of Bidadari

According to the Nature Society Singapore's Bird Group, this green space, which has been observed since 2009, had yielded 164 species of birds, or 39.6% of the 414 recorded species of birds in Singapore, as of October 2019. Of these, four are globally threatened species (Table 1).

Table 1. List of globally threatened bird species recorded at Bidadari.

IUCN Status	**Species**
Critically Endangered	Yellow-crested Cockatoo (*Cacatua sulphurea*) [Introduced]
Vulnerable	Long-tailed Parakeet (*Psittacula longicauda*) Javan Myna (*Acridotheres javanicus*) [Introduced] Brown-chested Jungle Flycatcher (*Cyornis brunneatus*)

Additionally, the area supported at least 13 species of nationally threatened resident birds including charismatic species such as the Oriental Magpie-Robin (*Copsychus saularis*) and Spotted Wood Owl (*Strix seloputo*) (Fig. 3).

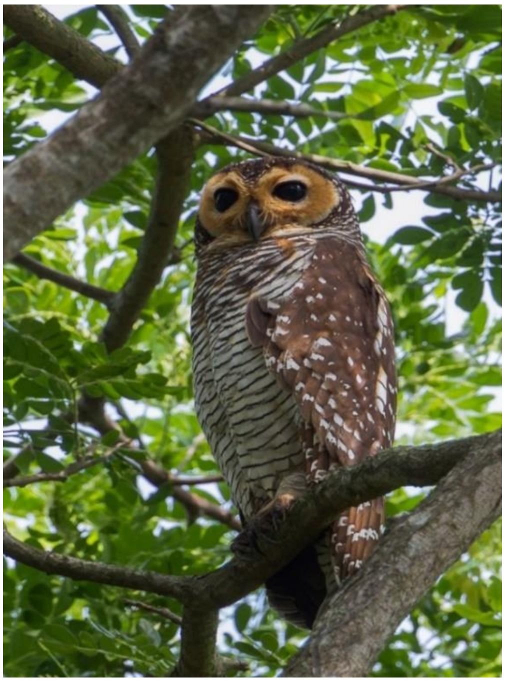

Fig. 3. A pair of charismatic Spotted Wood Owls are regularly observed roosting in the large fig trees around Bidadari. (Photo credit: Francis Yap)

Of the 164 species recorded for the area, 70 species (42.7% of Bidadari's bird list) were passage migrants or winter visitors such as the Oriental Dwarf Kingfisher (Fig. 4), and a further 94 species (57.3% of Bidadari's bird list) were residents.

Fig. 4. The stunning Oriental Dwarf Kingfisher (*Ceyx erithaca*) was one of 70 species of migratory birds that had been recorded at Bidadari. (Photo credit: Francis Yap)

In terms of dietary preference, insectivores comprised the most numerous feeding clade at Bidadari (Fig. 5). The area also supported an exceptionally high diversity of carnivorous avifauna as well, ranging from the resident Crested Goshawk (*Accipiter trivirgatus*) and migratory sparrowhawks (Fig. 6) that specialised in capturing birds to a wide variety of kingfishers and owls that consume terrestrial prey.

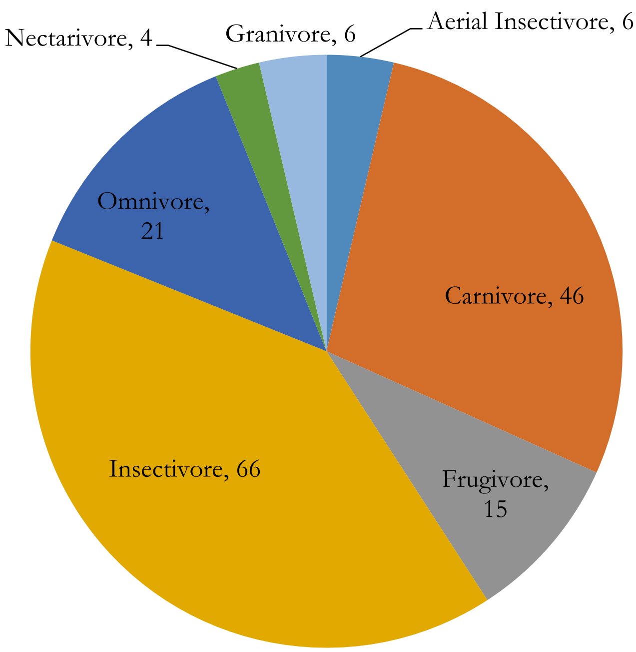

Fig. 5. Dietary preferences of the birds recorded at Bidadari.

Fig. 6. The migratory Japanese Sparrowhawk (*Accipiter gularis*) is a ferocious hunter of smaller birds regularly seen at Bidadari. (Photo credit: Francis Yap)

With regard to activity zones, habitat complexity at Bidadari had developed to the point where it was able to sustain a range of bird species that inhabit every vegetation layer (Fig. 7). The proliferation of Albizia (*Falcataria moluccana*) resulted in the formation of a viable canopy which also encouraged further growth of the shade-dependent epiphytes and other understorey species in addition to the extant Tembusu (*Cyrtophyllum fragrans*) and other trees that were not felled during the grave exhumation.

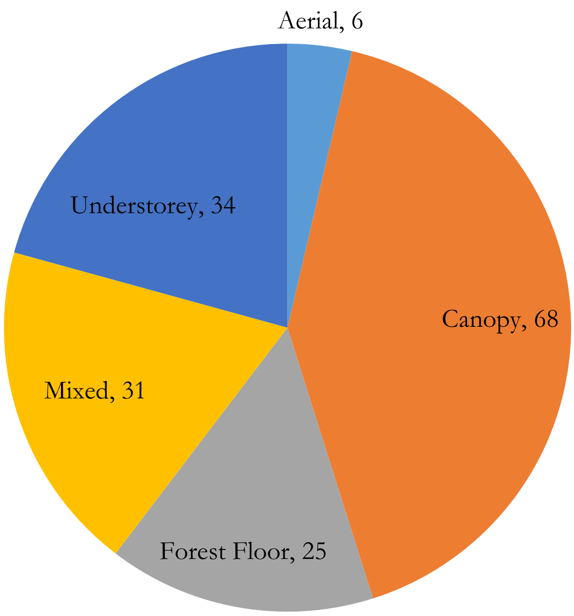

Fig. 7. Preferred activity strata of the various bird species recorded at Bidadari.

Many migratory species used Bidadari as a transit point on their way to their main wintering grounds in Indonesia and beyond. Peak avian diversity and abundance were observed from September through November during autumn migration and again from March to April during the return journey in Spring. A small number of species spent the entire winter at the green space. It was unclear why Bidadari was such an attraction to migratory birds; however, research from other urban cities such as Chicago and Toronto suggested the following:

1. Location – The wooded area at the Muslim cemetery was elevated compared to the surrounding landscape. This feature, combined with the low-rise land use of the surrounding landscape (Mt Vernon Columbarium, Cedar Girls Secondary School, Maris Stella High School and private housing), suggested that the area stood out to migratory birds as a sufficiently large green space for transit.

2. Land Use – It was fortuitous that the present land use around the site was restricted either to diurnal hours (schools) or was temporary in nature (funerals). This meant that at night when most of these birds migrated, the area was a dark(er) patch surrounded by a sea of lights. Studies in other highly built-up areas such as New York's Central Park had shown that migratory birds associate areas of darkness with areas of natural habitat and were drawn to it, especially during periods of bad weather.

3. Disturbance – In contrast to many other urban green spaces in Singapore, human disturbance at this site was very low. The only concrete path through the area started from the western boundary (visible from Fig. 1) and skirted around the south-western boundary of the site before running along the distinct boundary between the woodland and the open grassy area and then rejoining Bartley Road in the north-east near Bartley Station.

   Away from the footpath, the ground was overgrown and uneven with numerous potholes created during grave exhumation. As expected, most of the birds and wildlife were concentrated around the more heavily wooded west and south-western region of the site, with edge effects and noise pollution from the busy Bartley Road a likely deterrent to biodiversity at the eastern end of the site.

Other wildlife

While birds were the main attraction at Bidadari, the well-wooded site was also home to a wide variety of other animals. A summary of notable fauna records is outlined below.

Insects

A 3-month survey of the site in 2012 uncovered 31 species of crickets, grasshoppers and katydids (Tan, 2012). Notably, Bidadari was found to be the only locality in Singapore for two species of cricket (*Tarbinskiellus portentosus* (Fig. 8) and *Trigonidium* sp.) and one species of katydid (*Euconocephalus mucro*), of which the latter was also locally abundant.

Fig. 8. Bidadari is the only known site in Singapore where the cricket *Tarbinskiellus portentosus* has been recorded. (Photo credit: Tan Ming Kai)

Besides that, forest-dependent and colourful butterfly species such as the Common Rose (*Pachliopta aristolochiae*) had been observed in the area.

Reptiles

Reptiles observed at the site included the distinctive Green Crested Lizard (*Bronchocela cristatella*) (Fig. 9) and Equatorial Spitting Cobra (*Naja sumatrana*). The presence of Green Crested Lizard was particularly notable as this native species co-existed with the invasive Changeable Lizard (*Calotes versicolor*) at Bidadari, one of the few urban green spaces where this occurred. The Green Crested Lizard used to be abundant throughout Singapore until the 1980s, when the introduction of the invasive Changeable Lizard subsequently outcompeted and pushed the former species back into our nature reserves and remaining fragments of mature woodland.

Fig. 9. Bidadari was one of the few urban green spaces in Singapore where the handsome Green Crested Lizard could be found. (Photo credit: Francis Yap)

Mammals

The Variable Squirrel (*Calloscirus finlaysonii*) was one of the most conspicuous mammals in the area. Introduced to the area 30 years ago, the species has increased in population in line with the improving quality of habitat. The species did not appear to be highly invasive. In the 30 years since its introduction, it had not spread too far from Bidadari, with its main stronghold centred around the wooded areas to the south and west of the site including Woodleigh Park.

Of greater interest was the small population of native Common Palm Civets (*Paradoxurus hermaphroditus*) (Fig. 10) that inhabit the site too, although their exact numbers and movements were presently unknown.

Fig. 10. A small population of Common Palm Civet inhabits the well-wooded environs around Bidadari. (Photo credit: Francis Yap)

Bidadari housing master plan

In 2013, HDB announced the master plan for a housing estate of over 90 hectares at the site of the former Bidadari Cemetery. In the master plan proposal, Upper Aljunied Road was realigned, and three new roads – Bidadari Park Drive, Alkaff Crescent, Woodleigh Link – were planned to serve the upcoming estate. A regional park of 10 hectares was planned in the heart of the estate. Under the masterplan, the park had to include a stormwater detention pond which would help prevent downstream flooding of the adjacent estate. Besides that, a greenway which extended north and south out from the park, and served as recreational connectivity to other housing plots within Bidadari, was also planned. One of the key urban challenges was to integrate an underground service reservoir together with the park to regulate supply to homes and boost water pressure during periods of high demand. The service reservoir tank was planned beneath a community lawn in the Bidadari Park to optimise land use.

Under the larger masterplan development, the HDB plots would change the original topography of area to optimise platform levels, and most trees in the district plots had to be removed. As a result, the greenery loss would be inevitable and impact the migratory birds hotspots adversely. To mitigate this, the park boundary was discussed and adjusted together with Nature Society to incorporate key areas with clusters of bird observations.

Objectives and strategies of landscape master plan

Two key objectives of the landscape master plan were to enhance habitats within Bidadari for biodiversity, with birds as the key indicator species, and to enrich the living environment through planned greenery weaving between the urban forms. Strategies were discussed amongst urban planners, architects, landscape architects and avifauna experts to design the district such that Bidadari would be able to continue to serve as a stopover site for migratory birds after development.

One of the key macro strategies or coarse level landscape treatment was to conserve the higher topography of the park such that it could remain as a landmark to the birds (Fig. 11). In terms of larger greenery connectivity, several Nature Ways would also be planned into the new town (Fig. 12).

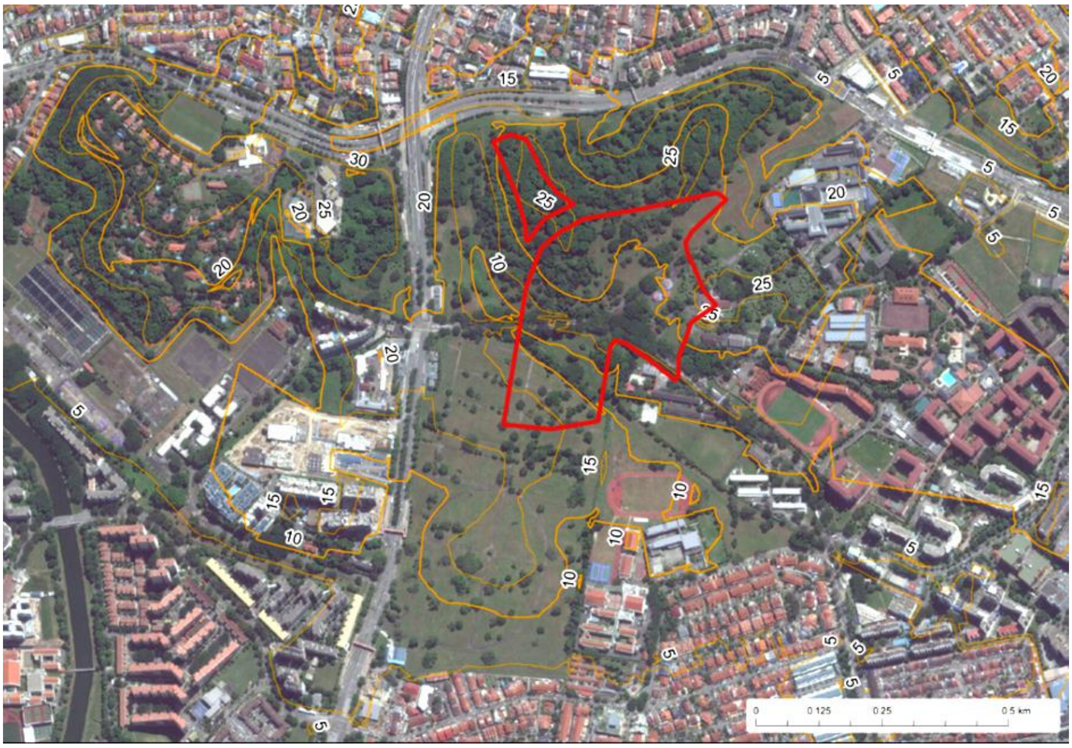

Fig. 11. The park boundary and hillock occupy most of the higher topography of the land.

Fig. 12. Nature Ways serve as larger greenery connections to the new town.

With the topography secured, the next step was to identify the potential habitat types in the estate. A core habitat area that had existing mature trees and *Ficus* clusters was identified within the regional park. The plan was to surround this core area with complementary and supplementary habitats areas around the estate (Fig. 13). In the planned network of greenery and habitats, other than the dominant greenway and streetscape greenery, plots of HDB precinct greenery and the various green roofs of HDB multi-storey carparks were considered as additional supplementary habitats to be planted with appropriate plants. The proposed stormwater detention pond, with its natural banks, was planned to be an additional supplementary habitat type previously not present in Bidadari Cemetery. Marshes, wet grassy areas, snags and rocks were planned for the pond area. A hillock was allocated as an additional complementary habitat, an area in which several sighting 'hotspots' were present due to the higher topography and more complex vegetation structure. The boundary of the hillock was refined in discussion with Nature Society to ensure that it was wide enough to provide a conducive environment for the birds to rest and refuel.

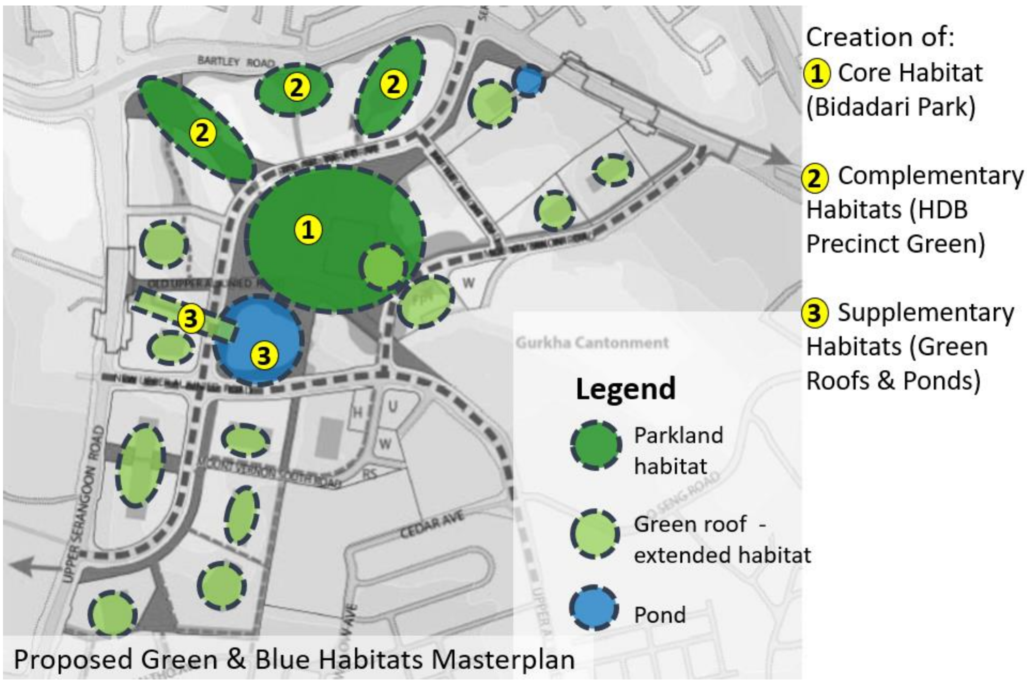

Fig. 13. Proposed green and blue habitats in the town.

Fine scale landscape strategies

At a finer scale, different landscape mosaics were considered within the park. These mosaics had a mixed vegetation structure in which birds could rest or move freely between different zones. The aforementioned *Ficus* clusters would serve as key stepping stones between the different landscape mosaics (Fig. 14). These landscape mosaics were carefully planned to ensure that park users could still use the park easily and safely, with active-passive zones identified and circulation planned through the park (Fig. 15–16). A more naturalistic and layered planting approach would be applied, and the core area would eventually be minimally lighted at night to remain a conducive migratory stopover for the birds.

Figs. 14. *Ficus* trees were identified for conservation and plotted as part of the park's landscape.

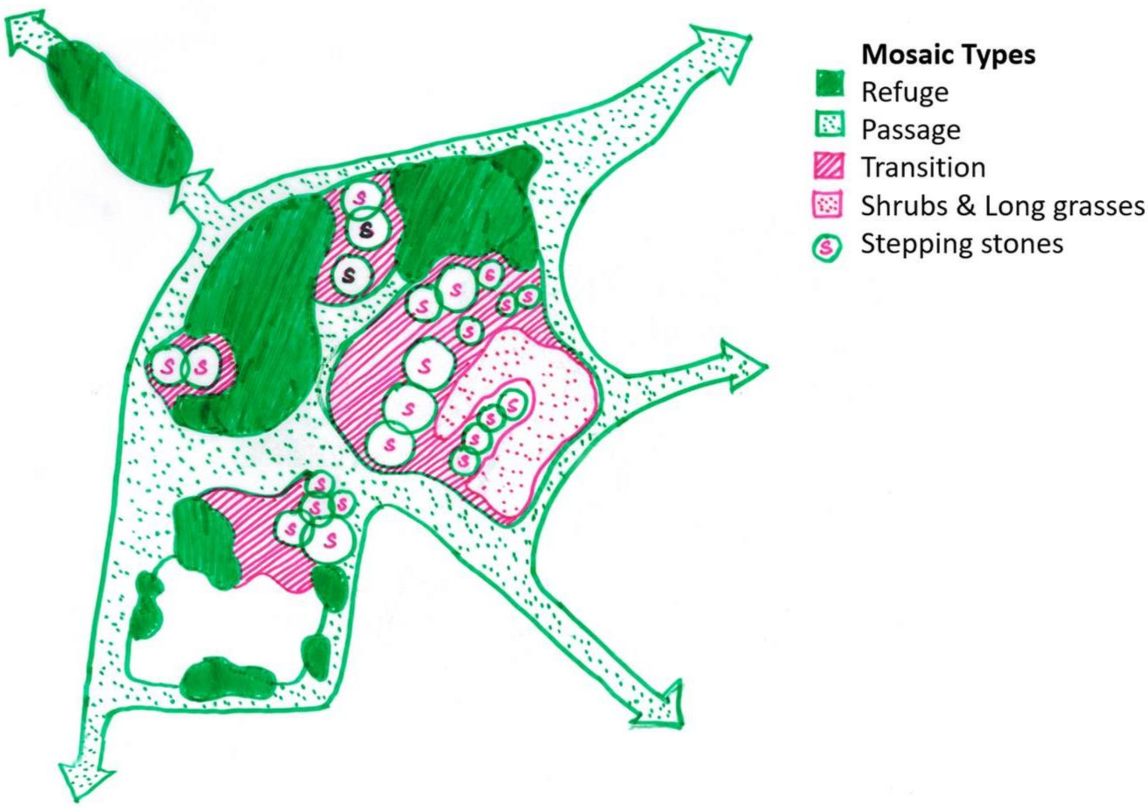

Fig. 15. Landscape mosaics planned in the park.

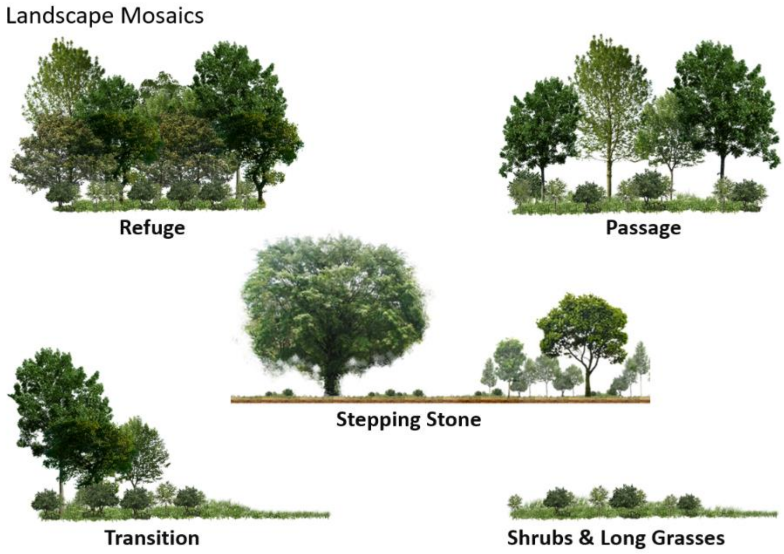

Fig. 16. Proposed landscape mosaic types for the park.

As part of the planned strategy to harness the existing greenery in the development boundary, healthy trees of ecological value were transplanted into the core habitat zone of the park. Over 300 trees were transplanted into a 4-hectare area, turning an area of grassland into a wooded area. Migratory birds were observed to return to the newly created woodlands as soon as the transplanted trees became established. Selected flora species would also be planted during the park development to build up the mosaics and vegetation complexity (Fig. 17). Trees that did not survive transplanting were retained as snags and logs to provide habitat for decomposers like fungi and various insects.

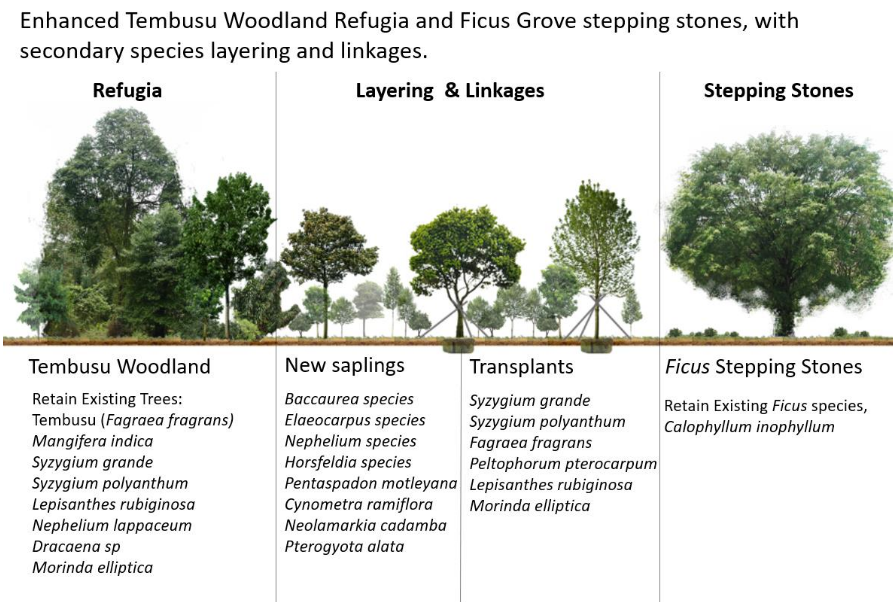

Fig. 17. Proposed refugia, layering, linkages and stepping stones for the park.

A 19 m-wide land bridge, which will serve as a link from Bidadari Park to Hillock Park and provide a safe passage for visitors and wildlife across Bidadari Park Drive, is being planted up (Fig. 18). Marshes and pond terraces are currently being created (Fig. 19). Structures such as raptor nest platforms will also be set up within the park as an interim measure for arboreal birds, while the layering of trees is shaping up.

Fig. 18. View of the land bridge linking the hillock (foreground) to the main park on 21 May 2023.

Fig. 19. View of the park and temporary pond towards the north, from Alkaff Lakeview on 25 May 2023.

Implementation – Park development

The park started construction at the end of 2019 and is targeted to be officially opened in 2024. A main heritage walk, observation deck, shelters, viewing sheds and woodlands nature trails are some of planned features of the future park. In due course, it is hoped that birdwatchers and nature enthusiasts will also be able to watch migratory birds at the new park. To determine the effectiveness of the landscape strategies, monitoring of the migratory birds will be conducted once the park is completed.

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CHAPTER 7

Nature Ways – Habitat Enhancement in Streetscape for Biodiversity

Lee Jia Hwa, Jason Yong Wai Weng & Oh Cheow Sheng

Introduction

We all prefer homes that are comfortable to live in with easy access to food; similarly, biodiversity habitats must be conducive for the diverse range of biodiversity, to cater to their different feeding habits and refuge needs. With more than 9,000 lane-kilometres of paved roads interconnecting the city-state of Singapore, covering 12% of the island's land area, the tension between nature areas versus urban spaces is a constant challenge for biodiversity to thrive and connect (Ministry of Transport, 2021). However, this could also be an opportunity if policies are designed to green up the city infrastructure.

Trying to create critical mass of greenery for our biodiversity is not by coincidence in Singapore. Government-led policies such as ensuring mandatory planting verges along all roads and green buffers along all developments have helped to achieve a certain amount of lush greenery across the island. Other policies and guidelines, such as gazetting nature reserves, easily accessible parks land distribution, tree conservation areas, Heritage Roads and Heritage Trees, have also been set in place to conserve areas with high biodiversity in a predominantly urban environment (National Parks Board, 2023b).

Developed by researchers at the Massachusetts Institute of Technology's (MIT) Senseable City Lab, Treepedia is an innovative metric tool that uses Google Street View panoramas to evaluate the Green View Index (GVI) of cities by measuring the amount of greenery as perceived along the street level in cities. According to Treepedia, Tampa is currently at the top of the list with the highest GVI score now at 36.15%. While Singapore is ranked as the second highest at 29.3% GVI (Fig. 1), its population density of 7,797 per square kilometres is six times higher than that of Tampa's (Massachusetts Institute of Technology, 2021). In a compact city state where it is critical to create a conducive living environment, greening strategies are essential to the softening of harsh infrastructures and the reduction of the urban heat island effect. The high global GVI score indicates the effectiveness of the implementation of our greening policies that provides residents with lush greenery. In addition, nature can also be integrated into the city with suitable habitats where biodiversity can thrive.

Fig. 1. Green View Index of Singapore. (Image credit: Treepedia)

NParks' Ecological Profiling Exercise

An Ecological Profiling Exercise (EPE) was launched in 2021 to conduct research based on the ecological profile of green spaces in Singapore (URA, 2022). By identifying core habitats that are the source of rich biodiversity and mapping out buffers of complementary habitats, an ecological profiling tool was developed based on a Geographic Information System (GIS) least-resistance pathway model that hypothetically projects the movement of six key fauna species (forest birds and mammals) between the source habitats.

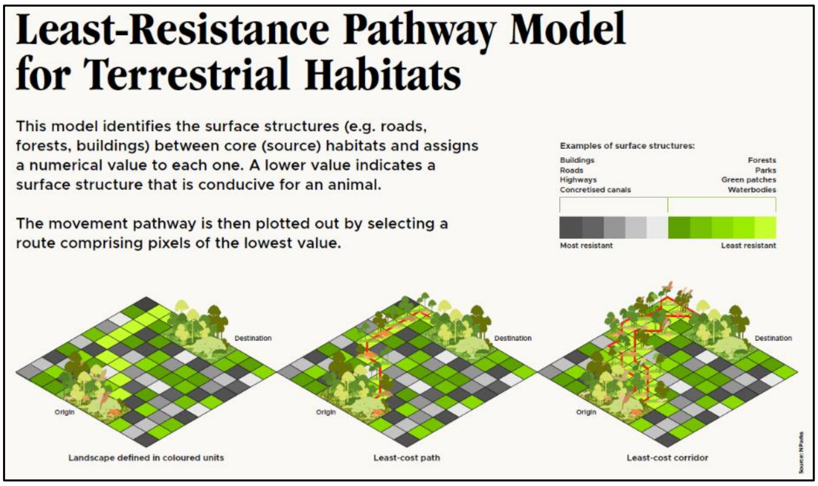


Fig. 2. Concept of Ecological Profiling Exercise (EPE) modelling.

The pathway behaviour is then modelled based on how easy or challenging it is for the fauna to move from one source habitat to another (Fig. 2). Ultimately, the projected connectivity is derived from the route(s) the key fauna species are likely to take to transit between core habitats. This allows us to better understand their behaviour for planners to consider where to avoid developing and conserve these routes to strengthen ecological connectivity. This also allows us to plan our Nature Ways routes to support connectivity. Research has also suggested that there is genuine potential for such passage ecology of nodes and corridors to serve as functional habitats for biodiversity, particularly when they are located nearer to more mature natural sources or patches (Sodhi *et al.*, 1999).

Fig. 3. Ecological Corridors derived from EPE.

Creating habitats with Nature Ways

Nature Ways are one of NParks' Streetscape division's initiatives for infusing biodiversity along our urban streetscape by connecting green nodes of biodiversity hotspots to create ecological corridors and enhance habitats. Nature Ways comprise complex multi-layered stratifications of tree canopies and a careful selection of biodiversity-attracting plants, and are part of an important strategy for biodiversity conservation. They enable immigration via ecological passages (facilitating the movement of fauna such as birds and butterflies between green nodes), and can thus reduce the extinction of population species due to secondary forest giving way to development. Stakeholders of land that is adjacent to the roadside reserves are also encouraged to apply the Nature Way scheme to their land and strengthen the ecological network.

There are currently 49 Nature Ways (Fig. 3 & 4) across the island, with an estimated total distance of 190 kilometres (as of FY22) created, and the target is to achieve 300 kilometres by 2030 as part of the Singapore Green Plan 2030 to remake Singapore into a green, liveable, and sustainable home (National Parks Board, 2023c).

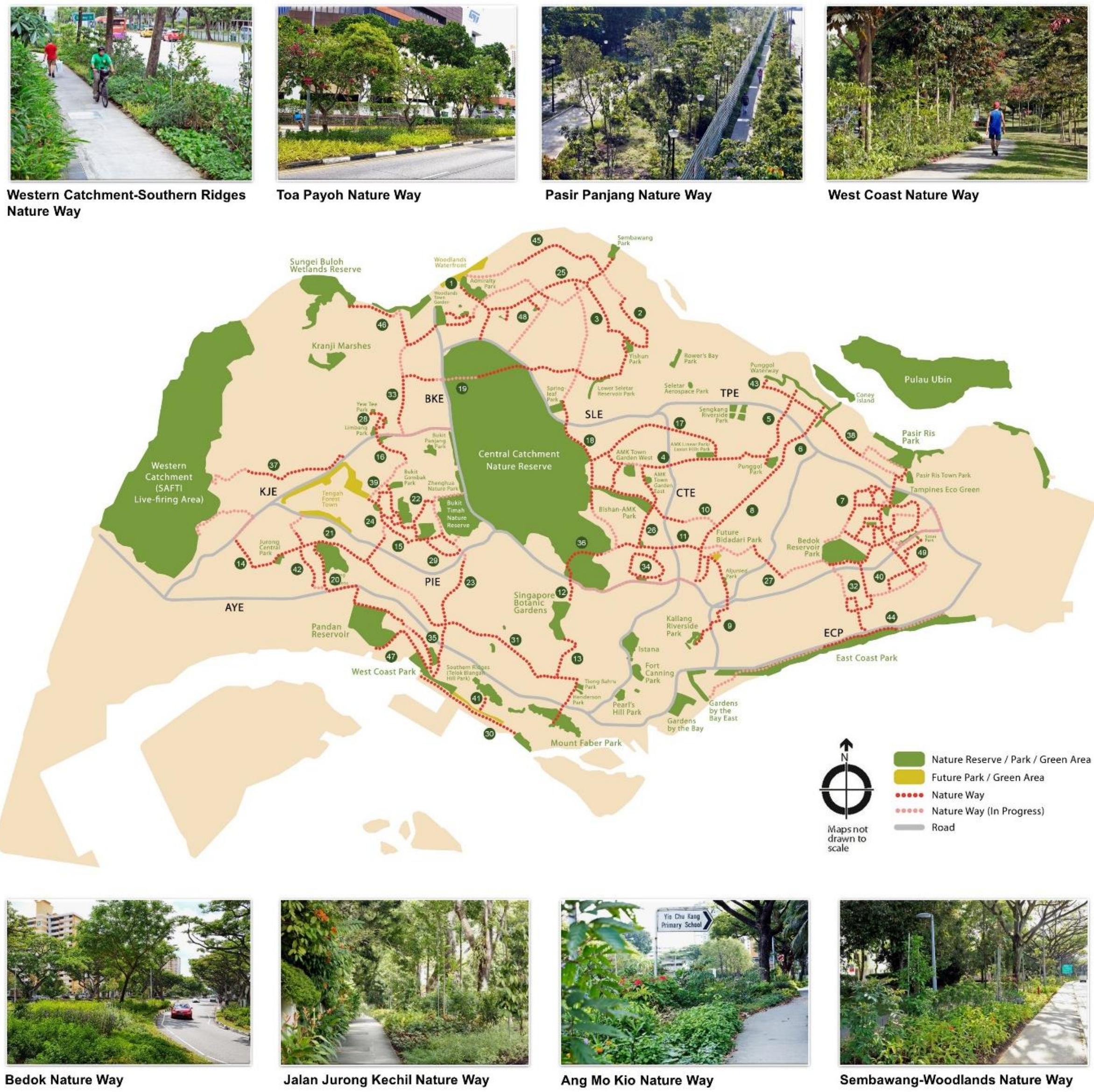


Fig. 4. Nature Ways progress update (as of FY22).

Designing for biodiversity

By replicating the natural structure of a forest (Fig. 5), Nature Ways encourage native fauna to forage and breed in the habitats within them, as food sources can be found at different levels along the streets. The emergent layer characterised by Dipterocarp or other taller canopy species, when fully mature, provides food for canopy-dwelling insectivorous birds and nesting sites for eagles and raptors (Fig. 6).

Fig. 5. Nature Way structure.

Fig. 6. An Oriental Honey Buzzard (*Pernis ptilorhynchus*) sighted on taller tree canopies along Keat Hong Nature Way (Old Choa Chu Kang Road).

The canopy layer is usually made up by the existing roadside trees which provide shelter and food for insectivorous birds as well as nectar-loving birds and butterfly species (Fig. 7 & 8).

Fig. 7. A Brown-throated Sunbird (*Anthreptes malacensis*) feeding on nectar sighted along Tampines Nature Way (Tampines Ave 5).

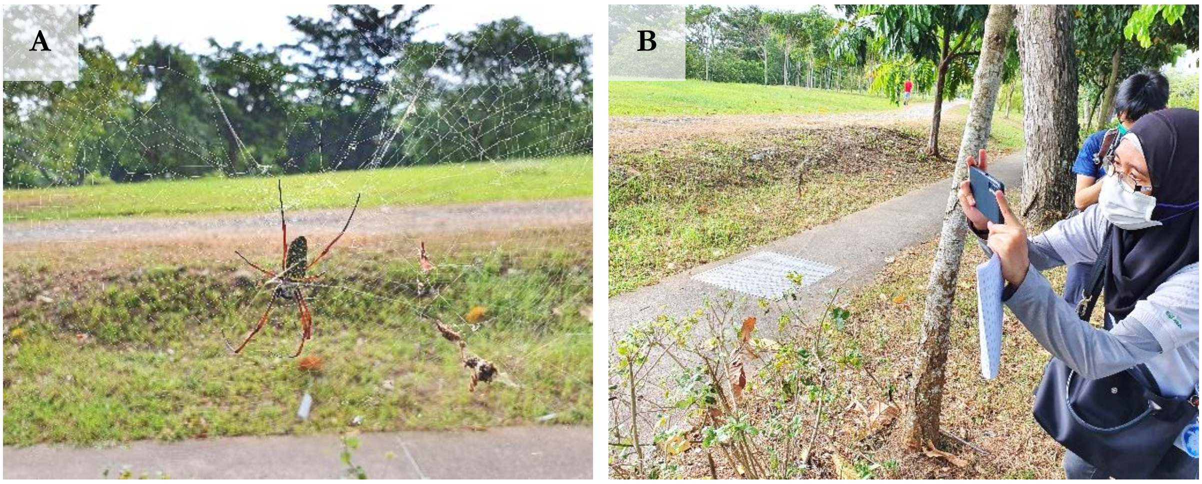
Fig. 8. A Yellow-vented Bulbul (*Pycnonotus goiavier*) eating fruits along Bishan Bidadari Nature Way (Ang Mo Kio Ave 1).

The understorey layer comprises smaller fruit-bearing trees that produce food sources for frugivorous birds and are also host plants for butterflies.

The shrub layer comprises flowering shrubs and the groundcover provides nectar for butterflies and nectar-loving birds. In addition to attracting other numerous insect species and spiders that are pollinators and food for birds, all these extra layers enhance the aesthetics of green infrastructure like roads and bring nature closer to the people (Fig. 9–11).

Fig. 9. A Lemon Emigrant butterfly (*Catopsilia pomona*) ovipositing along Ang Mo Kio Nature Way (Ang Mo Kio Ave 8).

Fig. 10. A Cruiser (*Vindula dejone erotella*) feeding on nectar flowers along Lornie Nature Way (Lornie Road).



Figs. 11. (A) A Golden Orb Web Spider (*Nephila pilipes*) sighted along Halus Nature Way (Sengkang East Drive); (B) Youth Nature of Stewards sighted a spider while doing a biodiversity survey on Nature Ways.

Enhancing species recovery to increase flora diversity

Besides planting bird- and butterfly-attracting plant species along the Nature Ways, NParks has also made a conscientious to enhance species recovery and re-introduce endangered plant species along the Nature Ways and other parts of Singapore. An example is the native Singapore Kopsia (*Kopsia singapurensis*), which was initially described by the first director of the Singapore Botanic Gardens, Henry Nicholas Ridley, from specimens sighted in Singapore in 1894. This rare species was collected in the wild in 1920 and was rediscovered in 2011 when it was collected from Nee Soon Swamp Forest (The Straits Times, 2023) (Fig. 12). The collected stem cuttings were then propagated and groomed at NParks' Pasir Panjang Nursery until they were established and ready to be introduced into Singapore's urban landscape (Fig. 13–15).

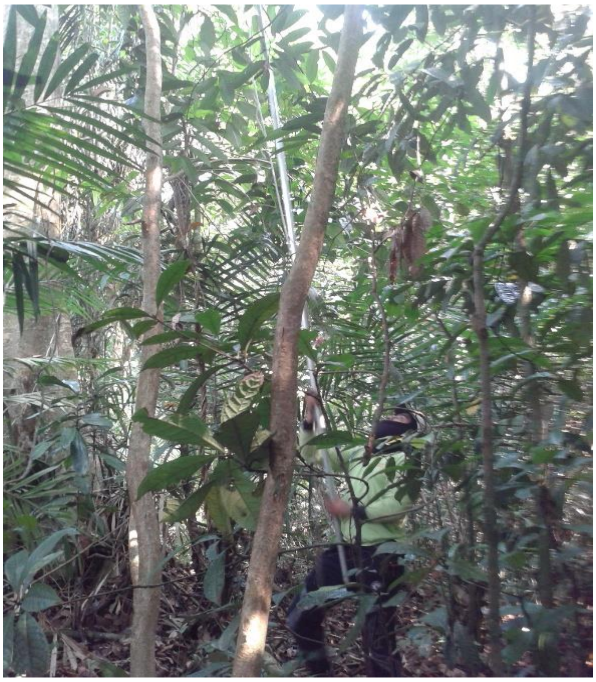


Fig. 12. Stem cuttings of Singapore Kopsia collected from a parent tree in Nee Soon Swamp Forest.

Fig. 13. Once the cuttings rooted, a landscape technician planted them in soil media incorporated with compost.

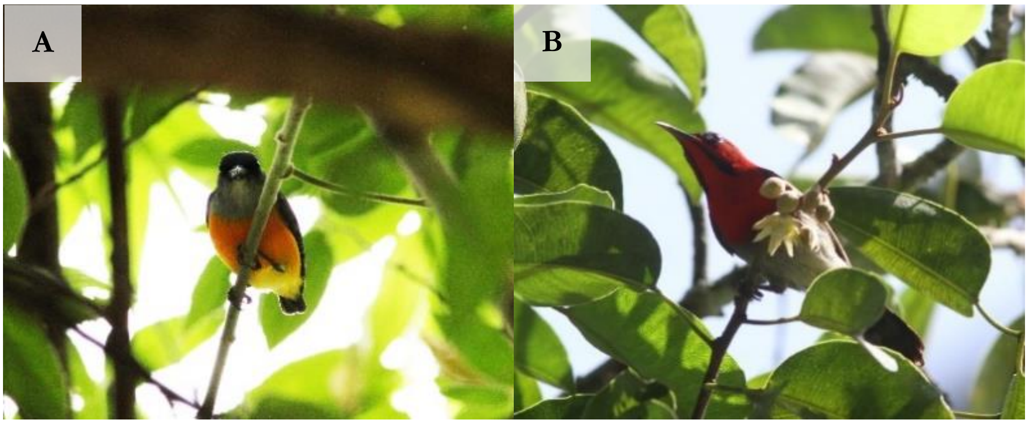
Fig. 14. Singapore Kopsia being nurtured and groomed at Pasir Panjang Nursery.

Figs. 15. Well-established planted Singapore Kopsia plants can now be seen along the streetscapes and parks of Singapore.

Singapore Kopsia has since been planted along Lornie Nature Way, Upper Thomson Nature Way and other parks and nature reserves in Singapore. Other lesser-known and vulnerable to critically endangered plant species being planted include Seashore Nutmeg (*Knema globularia*), Melunak Pusat Beludu (*Pentace triptera*), *Margaritaria indica*, Sea Beam (*Maranthes corymbose*), Upper Hill Dipterocarp (*Shorea platyclados*), Resak Irian (*Vatica rassak*), Chendarah (*Horsfieldia irya*), Wild Tamarind (*Cojoba arborea*), and Menterbang (*Aidia densiflora*).

Monitoring success indicators of biodiversity sightings

During the development of Nature Ways, the National Biodiversity Centre conducts pre-planting and post-planting surveys to monitor species sightings. These surveys may also be part of citizen science programmes to engage various stakeholders such as members of Nature Society (Singapore), the community and students, while instilling ownership. Observations from these surveys appear to indicate that the addition of Nature Ways often resulted in an increase in bird (Fig. 16.) and butterfly species sightings. When Nature Ways are adjacent to parks, they enhance habitat diversity, leading to increased overall biodiversity.



Figs. 16. (A) An Orange-bellied Flowerpecker (*Dicaeum trigonostigma*) feeding on fruits at Bishan-Ang Mo Kio Park; (B) A Crimson Sunbird (*Aethopyga siparaja*) feeding on nectar flowers near Windsor Nature Park.

Figs. 17. Youth Stewards of Nature spotted a bird's nest on a Red Powderpuff Plant (*Calliandra emerginata*) along Simei Nature Way (Simei Road).

Figs. 18. A bird’s nest spotted on Asam (*Elaeocarpus mastersii*) along Punggol Central Nature Way (Punggol Central).

The increased sightings and numbers of birds and butterflies, and observations of birds' nests (Fig. 17 & 18) at Nature Ways attest that Nature Ways have resulted in the creation of habitats for various faunal species.

Nature Ways can also serve to educate the public through on-site interpretative signage (Fig. 19) that contains species information of the plants growing there and the animals that may be attracted to the area. The signage is usually installed using funds from public, private and people (3P) sponsorship through the Garden City Fund (Garden City Fund, 2023).

Fig. 19. Grassroot Advisors, students and members of the community standing around an educational interpretative sign at the launch of Tampines Nature Way.

Nurturing future green guardians

More opportunities are also created for community to appreciate nature and get involved with citizen science participation such as SGBioAtlas (National Parks Board, 2023a), where records of any species sightings can be documented with a mobile application.

Tree planting constitutes a major portion of the implementation of Nature Ways. With the launch of the OneMillionTrees movement in 2020 to plant a million more trees across Singapore by 2030, NParks has worked closely with key partners including the Friends of the Parks communities, Community in Nature (CIN) schools, Community in Bloom (CIB) gardeners, volunteers, nature groups, corporate partners, other organisations, as well as members of the public to champion initiatives surrounding tree planting efforts (National Parks Board, 2023d).

NParks has also enlisted the help of youths to "adopt" Nature Ways through the "Be a Nature Way Steward" project, which is part of the Youth Stewards for Nature (YSN) programme since it was initiated in 2021 (National Parks Board, 2023e). The six-month YSN programme gives youths who are interested in horticulture, landscape architecture, environmental studies, biological or life sciences the opportunity to be involved in work groups mentored by NParks staff, in which they assist in the ideation and/or implementation of a real-world project (Fig. 20).

Figs. 20. Youth Stewards of Nature in action planting a tree along Simei Nature Way along Simei St 1, as part of the OneMillionTrees movement.

Conclusion

Singapore has evolved its streetscape greening strategies by incorporating design concepts of structural complexity and species diversity in the planting scheme for Nature Ways. This shift from the traditional monotonous planting scheme can help increase the resilience of streetscape greenery to any epidemic outbreaks (e.g., host-specific pathogens targeting on single plant species). The multi-layering of trees in Nature Ways also allows for the seamless replacement of greenery and shade when older trees die and younger trees grow to take their place – much like how a forest regenerates itself. As such, apart from enhancing habitats and creating more food resources for biodiversity, having more Nature Ways also prepares the streetscape for successional phases.

Imagine if all roads in Singapore are planted up intensively with Nature Ways – this will result in a network of linear ecological webs with all the roads inter-connecting to all corners of the island! Not only will we get to enjoy the shade under these green canopies, but everyone can also get closer to nature, enjoying a colourful and biodiverse environment all around Singapore.

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CHAPTER 8

Eco-Link@BKE: Restoring for Connectivity

Sharon Chan, Sunia Teo, Chong Han Wei, Chung Yi Fei & Cheryl Chia

Background

The 11-kilometre Bukit Timah Expressway (BKE) was completed in 1986 to facilitate the flow of vehicular traffic to the north of Singapore, easing congestion for residents living along Bukit Timah Road. Its construction divided a once continuous patch of rainforest, the Central Nature Reserve, into two separate forested areas – Bukit Timah Nature Reserve and Central Catchment Nature Reserve. This had consequences for the native flora and fauna of the rainforest.

The BKE became a physical barrier separating the two Nature Reserves, isolating habitats and populations. Most endangered species of forest wildlife are elusive in nature, and avoid human disturbances such as major roads. With populations of these animals thus isolated from each other by the six-lane BKE, inbreeding depression, which is the reduced biological fitness in a population due to breeding of related individuals, is likely to occur and could lead to their local extinction.

However, being situated between the two forests, the BKE inevitably led to the increased occurrences of vehicle-wildlife collisions. Between 1994 and 2014, there were two Sunda Pangolin (*Manis javanica*) deaths on major roads around the nature reserves. This species of pangolin is classified as critically endangered on the International Union for Conservation of Nature Red List of Threatened Species. Other common roadkill include the Common Palm Civet (*Paradoxurus hermaphroditus*), Long-tailed Macaque (*Macaca fascicularis*), and a number of reptile species.

Objectives of building the Eco-Link@BKE

A feasibility study of the wildlife road crossing project was conducted, to determine the possible locations and the concept design of the link between the two reserves. Taking into consideration the wildlife in the vicinity and the natural landscape of potential locations, it was decided that a wildlife bridge overpass built over the BKE was a better option than a wildlife viaduct. A wildlife overpass would result in less impact on traffic flow on the expressway, cause less unmitigated noise, and produce in a smaller environmental footprint. The wildlife overpass that was conceived in 2013 is now known as the Eco-Link@BKE.

The Eco-Link@BKE is one of Singapore's efforts to address fragmentation by habitat restoration, hence, facilitating biodiversity conservation in our urban landscape. The key objectives of the Eco-Link@BKE were:

1) reinstating the connectivity between two Nature Reserves, Singapore's largest primary and secondary forests,
2) documenting the animals that reside at these sites that would potentially use the Eco-Link@BKE,
3) documenting the changes in species composition, and
4) investigating the population trends of the target species – pangolin, mousedeer, wild boar, and deer – in the vicinity of the bridge.

The Eco-Link@BKE would be the first overhead ecological corridor to be built in the region. Shaped like an hourglass, it would be widest at both ends and tapered towards the centre of the bridge, which would be 50 metres wide at its narrowest. When completed, it would enable animals, birds, and insects to move freely along the connecting bridge, allowing for the effective exchange of native plant and animal genetic materials between the two nature reserves. In the longer term, the Eco-Link@BKE would help restore the ecological balance in these fragmented habitats and provide a conducive environment for our biodiversity to thrive.

The target species for the Eco-Link@BKE included terrestrial mammals with restricted home ranges, species with a higher incidence of roadkill, and threatened species such as the Sunda Pangolin, Common Palm Civet, and Lesser Mousedeer (*Tragulus kanchil*). Disturbance-sensitive forest birds, insectivorous bats, and other invertebrates were also projected to benefit from the construction of the Eco-Link@BKE.

Prior to the construction of the Eco-Link@BKE, biodiversity monitoring surveys were carried out by nature groups, tertiary institutions, government agencies working closely with National Parks Board (NParks), to collect baseline data for future comparison and assessment. Camera traps and nocturnal faunal surveys also recorded several rare and geographically restricted mammals, including the Lesser Mousedeer and Sunda Pangolin. Forest birds such as barbets, babblers, and bulbuls were also observed in the vicinity of the proposed site of the Eco-Link@BKE. These species are vulnerable to local extinction and would not cross the expressway without a wildlife bridge.

Site selection and utilisation

The site selection was crucial for minimising land clearance. Although the BKE drove through the forests between BTNR and CCNR, the natural landscapes were maintained with knolls and valleys. Based on the topography of the area, an overhead eco bridge was planned to be at a site with two knolls on either side of the expressway (Fig. 1).

Fig. 1. Location of the Eco-Link@BKE.

To ensure undisrupted traffic flow and minimise the footprint of the construction, effective site utilisation was highly emphasised (Fig. 2). The construction maximised the use of precast technology while stringent earth control measures were implemented.

Fig. 2. The traffic flow along the BKE was maintained throughout the construction phase, while the inconvenience for the commuters along BKE was minimised.

Landscape concept plan

The landscape concept for the wildlife bridge was a lowland forest habitat which would have great value both as a habitat as well as for wildlife. This habitat would have three key layers where the upper layer would be all tall trees while the lower level would be made up of saplings of several species. The ground vegetation would often be sparse and comprise mainly small trees and shrubs. By replicating these habitats in the bridge, it would be able to serve as a conducive corridor for wildlife by providing food, cover, and protection to many different animals, including small mammals, birds, and many insects.

The bridge was designed to withstand the weight of more than two metres depth of soil and tropical trees. The skyrise greenery concept guided us on the soil depth and soil type to be introduced on the bridge. The backfilling materials consisted of 10 different layers (Fig. 3). The top soil and the loamy soil were the major components of the backfilling materials which included a geogrid to help anchor the roots. These two layers would hold certain level of water and support the tropical plant to be grown on the bridge. To prevent additional weight caused by waterlogging, a gentle gradient was created at the base of the bridge, so that the water infiltrated through the soil would be discharged down the bridge into the storm drain.

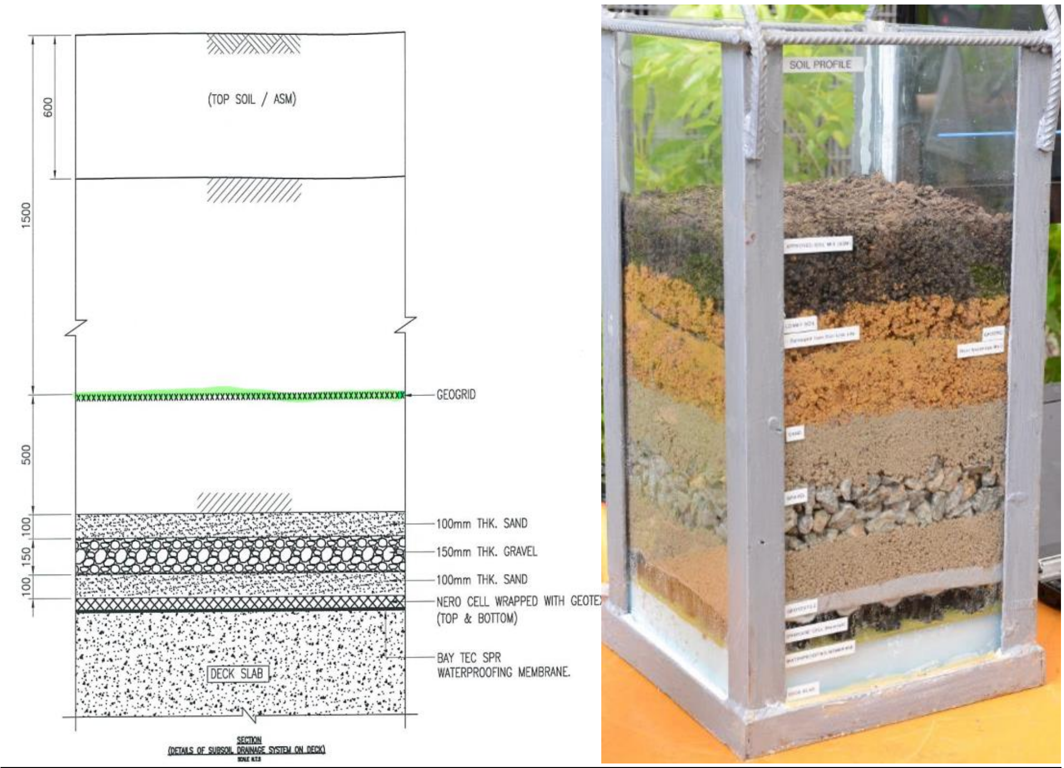
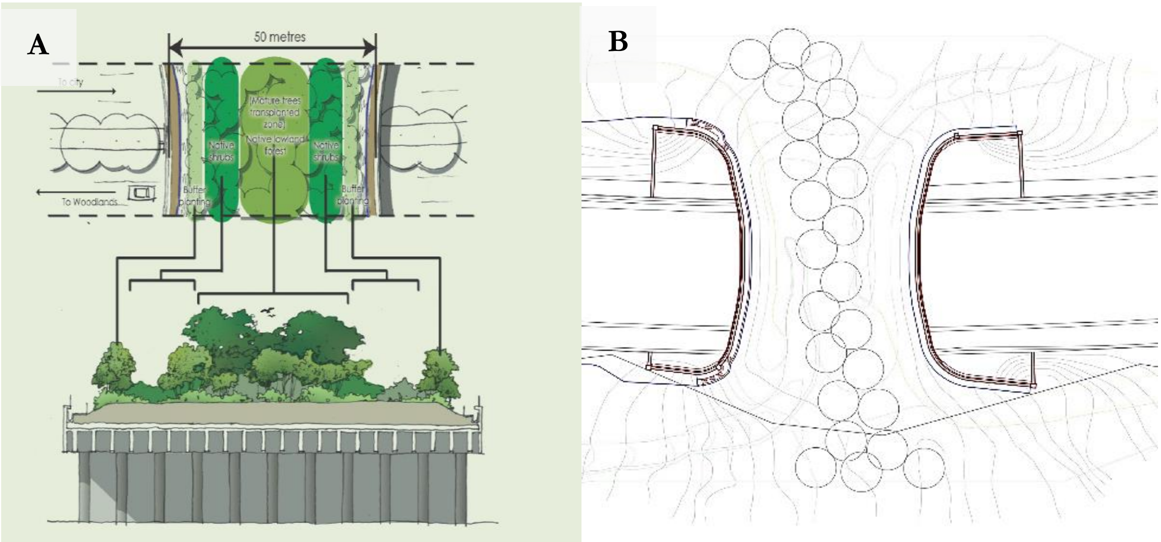


Fig. 3. A diagram and a model showing the soil profile on the Eco-Link@BKE. From top to bottom, the layers are top soil, loamy soil, geogrid, loamy soil, sand, gravel, sand, geotextile, drainage cell, and water proofing membrane.

Before the establishment of the greenery, the weather conditions on the bridge were very harsh with high sunlight intensity, high wind speed, low humidity, and high ambient temperatures. The pioneer native plants were carefully selected based on the characteristics, such as tolerance to extreme conditions on the bridge, provision of food and shelter, and hardiness. Some of the species that successfully established on the bridge were Elephant Apple (*Dillenia indica*), Petai (*Parkia speciosa*), Sandy-leafed Fig (*Ficus heteropleura*), Singapore Rhododendron (*Melastoma malabathricum*), Campanula Orchid (*Dianella ensifolia*), Cane Reed (*Cheilocostus speciosus*) and others.

In general, more shrubs were planted at the edge to create a barrier between the interior and the disturbed edges while most of the taller forest trees were planted in the middle that formed the backbone of the landscape ecosystem (Fig. 4). More than 3,000 native plants were used to lay the foundation of a seamless forest between the two nature reserves across the Eco-Link@BKE.



Figs. 4. (A) General planting plan of the Eco-Link@BKE where hedging created by shrubs minimise disturbances on the interior, and the trees were planted in the middle; (B) Diagram showing the gradient of the soil and proposed locations of the big trees.

To reduce competition from weeds and tall grass, grass cutting was scheduled every two weeks. This ensured that the fast-growing turf grass would not compete with the young native plants for nutrients. Strict maintenance regime was crucial for the early succession and establishment of the native plants.

Many lower quality habitats within the reserves and in the vicinity of the Eco-Link@BKE were also reforested to speed up the regenerating process. The different stages of the building of the Eco-Link@BKE and the progressive maturing of the ecosystem restoration from April 2013 to 2019 are shown in Fig. 5 to 8.

Figs. 5. Aerial photographs of the Eco-Link@BKE project taken in (A) April 2013 and (B) August 2013.

Figs. 6. Aerial photographs of the Eco-Link@BKE project taken in (A) November 2013 and (B) June 2014.

Fig. 7. Aerial photograph of the Eco-Link@BKE project taken in 2017.

Fig. 8. Aerial photograph of the Eco-Link@BKE project taken in 2023.

Species monitoring

While there were no pre- and post-development studies carried out on the effects of the BKE on the fragmentation of the two reserves, it was widely accepted that smaller fragments of forests supported fewer species and would degenerate over time and thus unable to support forest specialist species in the long term, based on studies in other places. Connecting the two fragments would, undoubtedly, have a positive impact on the biodiversity in both reserves. However, detailed and long-term monitoring studies would need to be in place to ascertain the effectiveness of the link for various groups of animals so that appropriate measures could be determined based on sound science. The monitoring data would assist in determining which target animal groups were not crossing the link and would prompt us to explore alternative ways to improve ecological connectivity in the future.

The use of camera traps began in 2011, to document and monitor the animals that would benefit from the construction of the Eco-Link@BKE. The native animals in Singapore's nature reserves were shy, cryptic, and nocturnal. This meant that intensive human resources were required if "traditional" forms of sampling such as line transects, visual surveys and pitfall traps were adhered to. Camera traps were a non-intrusive way to study and monitor the movement of animals. By employing camera traps, surveyors were able to minimise disturbances, entering the forest only during deployment and retrieval. The camera trap, once deployed, would continuously capture any movement of animals in its visual path.

For this study, three sites were identified: one in Bukit Timah Nature Reserve, one in Central Catchment Nature Reserve and one in Chestnut. The first two sites were identified as habitats that would benefit directly from the Eco-Link@BKE, while the third one was identified as the control site. These three sites were surveyed five times, in three different monitoring events (Table 1).

Table 1. Schedule of the five survey years and their respective monitoring events

Year	Monitoring event
2011 & 2012	Pre-construction monitoring
2015	Post-construction monitoring
	Pre-habitat enhancement monitoring
2018 & 2021	Post-habitat enhancement monitoring

By deploying camera traps at pre-determined Global Positioning System (GPS) coordinates, we were able to monitor not only the animals' presence during the survey year, but could also perform analysis of the long-term monitoring results.

Conclusion

The fauna survey of terrestrial vertebrates, birds and butterflies recorded an impressive species list on the Eco-Link@BKE. In total, more than 101 different faunal species were sighted in this human-made ecological overpass. This could be attributed to the intensive re-wilding of the bridge by planting native plants in a stratified layer, which had attracted other ecosystem engineers as well – the butterflies and the birds. Hence, it was important to record the species richness on the bridge to better understand the ecological succession process.

This project highlighted the importance of a long-term monitoring research project that allowed researchers to track the species detection changes over the years. Species of interest such as the Sunda Pangolin (Fig. 9 & 10) and Lesser Mousedeer (Fig. 11) could be monitored to assess the effectiveness of the bridge with respect to each species and the results can hence inform the relevant, important management decision to ensure the population could be sustained on a long-term basis. A 30-day deployment regime and alternate year monitoring provided a sufficient sampling method that could be easily replicated for long term monitoring.

The alternative year constant monitoring could be employed by environmental impact assessment/biodiversity impact assessment studies in order to chart a more accurate qualitative and quantitative biodiversity study for their field evaluation. Hence, planners and land-owners would be able to make more informed decisions of their land use and management plans based on sound science.

Based on the regular monitoring records of the Eco-Link@BKE, which has been established for at least ten years, we have achieved our mission of conserving native biodiversity, in particular, the rare forest-dependent species, and ensuring that they would be able to thrive in an urban biophilic city like Singapore.

Fig. 9. A camera trap captured a Sunda Pangolin (bottom left) crossing the Eco-Link@BKE in 2018.

Fig. 10. A camera trap captured a Sunda Pangolin crossing the Eco-Link@BKE in 2021.

Fig. 11. A Lesser Mousedeer was captured in front of the camera trap at the Eco-Link@BKE.

CHAPTER 9

Seeding Inter-agency Exchange behind the Restoration of Kallang River, focussing on Bishan-Ang Mo Kio Park, as an Ecological Connector

Damian Tang & Mayura Patil

Introduction

The ambitious Kallang River master plan was first conceived in 2006 by the National Parks Board (NParks), in collaboration with PUB, Singapore's National Water Agency. Led by PUB, the project began as a straightforward plan that required only a planting palette from NParks to green up both sides of the canal as the Marina Barrage was getting constructed, turning the tidal waterway into a freshwater canal. The greening project took a turn when the master plan was proposed, involving the naturalisation of the canal – novel habitats would be weaved with the river, integrating vegetation and wildlife with water.

The master plan was presented with various landscape strategies and a visionary image that illustrated the possibilities of waterways and water bodies that could be transformed in different phases – from its current concrete state into an ecologically and aesthetically enhanced vibrant space for people and biodiversity. It aimed to integrate the canal with several green spaces, including Bishan Park (the previous name for Bishan-Ang Mo Kio Park), and to enhance the biodiversity along the Kallang River. This plan was approved from the then CEO of PUB, Mr. Khoo Teng Chye, and then CEO of NParks, Mr. Ng Lang, who set the vision for the projects.

However, there were many challenges and a lack of technical experts to implement these ideas. It would require strong collaboration between both PUB and NParks and the recognition of landscape planning expertise to realise the master plan. Damian Tang, then with NParks, was seconded to PUB for six months and during his secondment, a 300-metre stretch of park connector along Kallang River was proposed to be redeveloped as a demonstration site under the PUB's ABC Waters Programme. The Kolam Ayer demonstration site was launched in 2008, and it became a vibrant green space by the river for community activities to be held and biodiversity to thrive.

The exchange of knowledge between NParks and PUB further bore fruit in the years that followed, with the successful redevelopment of Bishan-Ang Mo Kio Park as a flagship project under the ABC Waters Programme.

Site analysis and precedent studies for the ecological restoration of Kallang River

1a. Site context

Fig. 1. Location of Kallang River. The Kallang River originates from the North of Singapore at the Lower Pierce Reservoir and flows through dense urban areas towards the Marina Bay at the South. (Image credit: Mayura Patil)

1b. Ecological potential of the site

The river stretches to approximately 10 kilometres, which could play a crucial role as an ecological connector between various habitats (Fig. 1). The origin of the river is in close proximity to primary forest vegetation as well as freshwater swamp forest, and old and young secondary forest patches. The river passes through various urban habitats such as neighbourhood parks, park connectors, linear green spaces, as well as large-scale recreational landscape areas towards the south of the river. The river has the potential to create suitable conditions for the growth of various habitats ranging from natural freshwater aquatic habitats to novel aquatic ecosystems towards the south.

1c. Water levels in the river

The water levels and the river profile varied along the entire stretch (Fig. 2). It was important to consider the need for maintaining certain water levels for the hydraulic capacity. The variation in the water level allowed for the creation of various types of habitats along the river stretch. The masterplan also had to consider the changes in the water levels after the intervention of Marina Barrage (Fig. 3).

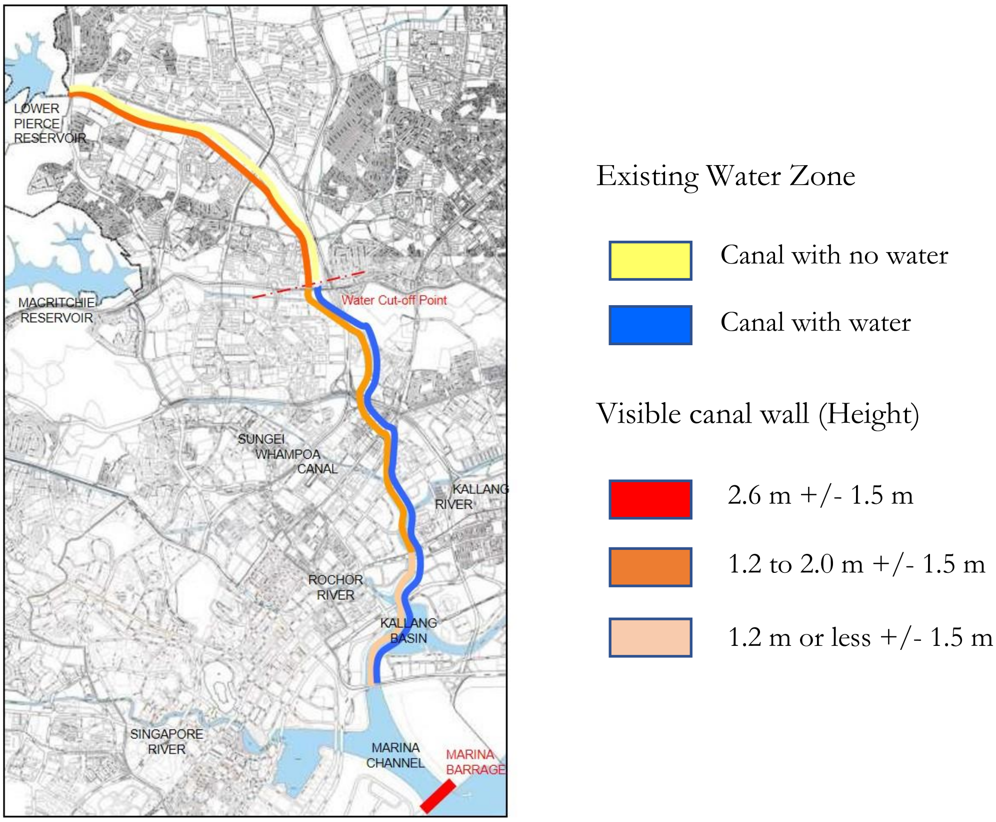


Fig. 2. Variation in water level and river profile along the longitudinal stretch of the river. (Image credit: Damian Tang, based on data from PUB, 2006)

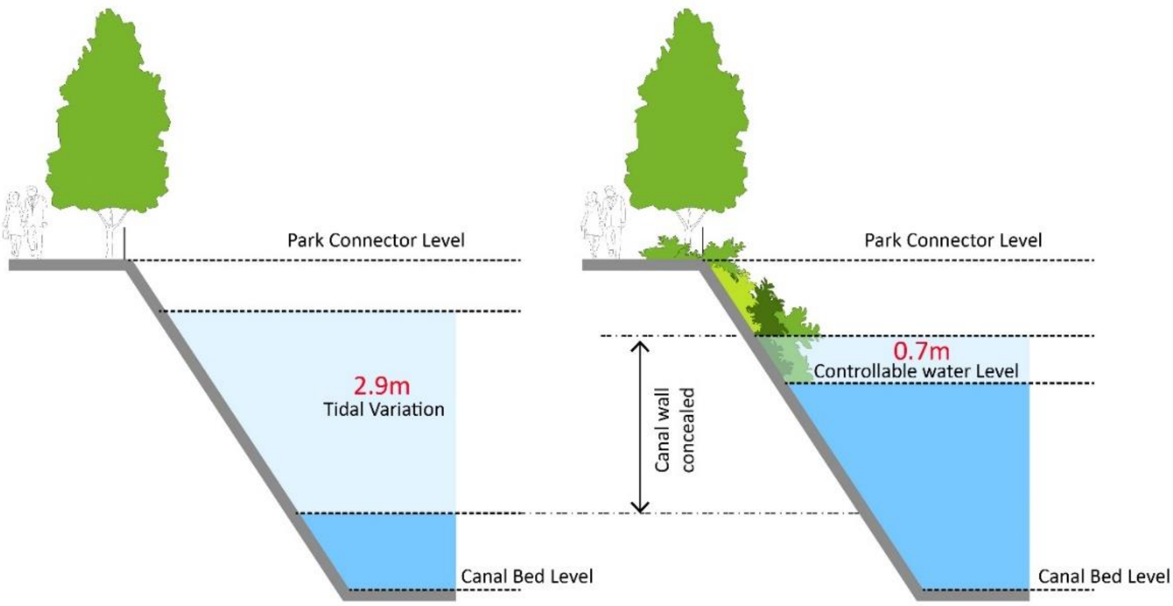
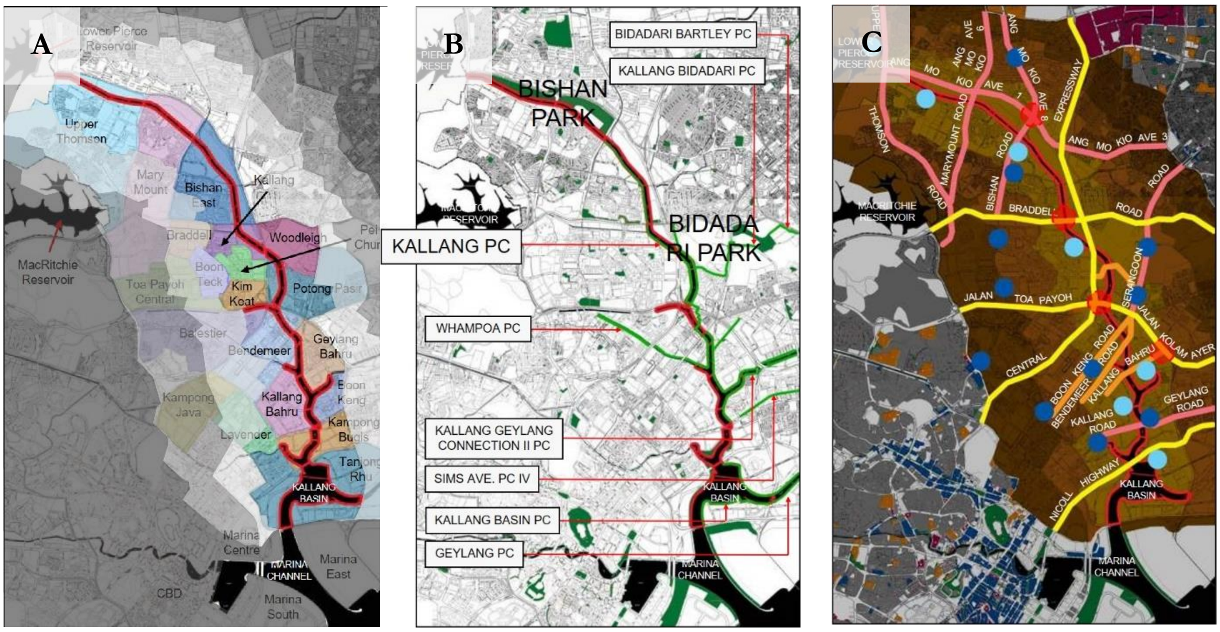


Fig. 3. Changes in the water level at Kallang basin before (left) and after (right) the intervention of the Marina Barrage (2006). (Image credit: Mayura Patil, based on data from PUB)

1d. Land use and constraints

The team studied GIS (geographic information system) maps to get a better understanding of the neighbouring areas and the surrounding catchment areas related to the river. The immediate neighbouring land use was studied to conceptualise ways to connect the users who would benefit from this project. Physical constraints such as expressways and other vehicular roads that intersected with the river were mapped to foresee potential issues in creating a continuous pedestrian and ecological links along the river (Fig. 4).



Figs. 4. (A) Neighbourhood towns and GIS mapping (proximity); (B) Parks and park connectors; (C) Site constraints. (Image credit: Damian Tang, based on GIS data, 2006)

1e. Learning from other success stories

The preliminary design vision for the Singapore river was to rejuvenate the river such that it would not only benefit the people but would also support flourishing biodiversity along the river edge. This would be the first project in Singapore of this scale where landscape and civil engineering experts had to work together. Hence, relevant case studies from different countries were conducted to encourage others to understand the potential of this site and to help them reimagine urban rivers.

Case study 1: In the 1890s, the Isar river in Munich, Germany was straightened and squeezed into a rigid canal. As a result, the water velocity and temperature changed unfavourably. To resolve these issues accelerating over the years, the Isar was reformed into a near-natural river in 1995 (Fig. 5). The new restorative design included flood protection features and achieved bathing water quality in the river.

Figs. 5. Isar River, Munich, Germany before restoration (left) and after restoration (right). (Photo credit: Mahida, 2013)

Case study 2: In the 1960s, the polluted Cheonggyecheon stream in Seoul was covered with concrete and a six-lane highway was built over it. This snatched away the potential of bringing Seoul's residents back to enjoy the stream. In 2003, the highway was torn down and the 600-year-old historical stream was restored by integrated engineering solutions, resulting in wide pedestrian landscaped corridors and accessible water with high water quality (Fig. 6).

Figs. 6. Cheonggyecheon Stream, Seoul, South Korea in 1960s (left) and 2003 (right). (Photo credit: Global Designing Cities Initiative, 2023)

Case study 3: From the 1820s, increased free trade caused overcrowding along the Singapore river which resulted in water pollution. The water quality degraded over the years and the river became devoid of marine life. In 1987, the river was cleaned up which attracted riverside commerce and residences. The revitalised river encouraged new recreational activities such as boating and attracted tourism.

Design vision

The Kallang River is approximately double in length than the similar precedent studies. It passes through areas of varying land use and has many site characteristics (Fig. 7). Hence, the masterplan had more constraints than what were posed in the case studies.

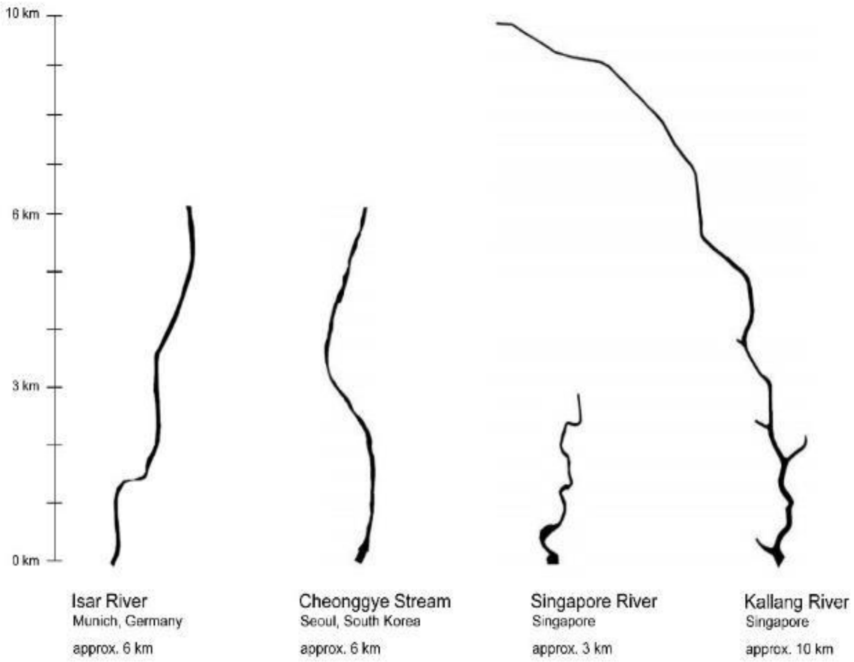


Fig. 7. Size comparison between case studies and the site. (Image credit: Damian Tang)

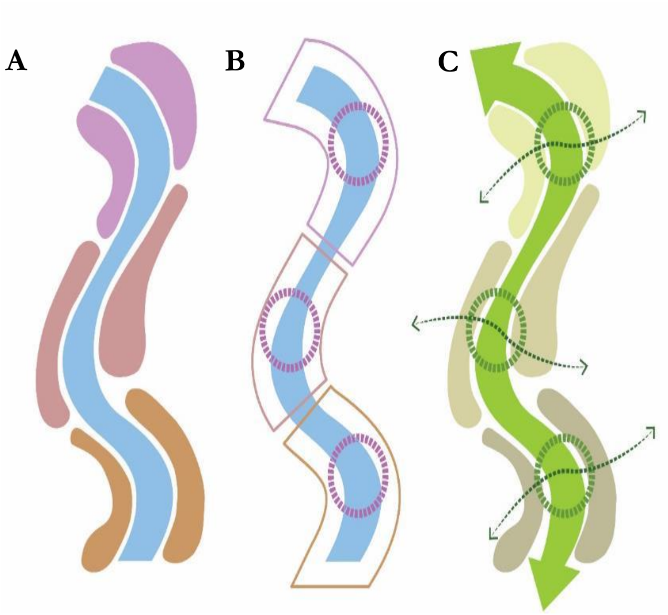
2a. Social and landscape zoning

The Kallang River aimed to transform the physical and social landscape of its adjoining neighbourhoods with the implementation of a coherent and consistent riverfront strategy.

Initially, PUB engineers were worried about bringing people in physical contact with the waterbodies, as this might be considered a health hazard, raising concerns to public safety. But they were also very keen on testing different programmes to activate the waterbodies especially the canal edges.

Landscape zoning was planned to give different characteristics to the river edge and create a distinct identity for the river. Different thematic zones were proposed along the river to reinvent the river as a new recreational destination. Lateral social and landscape connections were envisaged to socially and ecologically connect the river to the city. A linear ecological connection was proposed to establish the river as an ecological corridor.

By finding the solutions to on-site constraints, a unified design strategy could thus be created. The river was divided into three different zones based on the water level and profile of the river (Fig. 8). Different zones allowed for distinct landscapes and riverine identity with various ecological habitats.



Figs. 8. (A) Landscape zoning; (B) Recreational nodes; (C) Lateral and linear landscape connections. (Image credit: Mayura Patil)

2b. Designing a habitat corridor

While designing an ecologically sensitive masterplan to improve biodiversity, it is important to analyse the source habitats. In urban landscapes, the source habitats are often large patches of greenery, such as nature reserves and vegetated parks. Although the effects of habitat fragmentation are under constant debate (Fahrig, 2017), many scientific studies show that habitat fragmentation may disrupt landscape connectivity, interfering with species dispersal and enhancing the risk of extinction for certain species (With, 2002).

Once the key patches are identified, it is necessary to find a way to connect them. Scientific research summarised landscape connectivity as a combined effect of (1) landscape composition (structural connectivity) and (2) the species' ability to move among the habitat patches (functional connectivity) (Tischendorf *et al.*, 2000). According to Tischendorf, corridors are narrow, continuous strips of landscape habitats that structurally connect patches. The 10-kilometre stretch of Kallang River provided the opportunity to create an ecological corridor that connects habitat patches along its course. In areas where connection is difficult, small vegetation areas should be identified as stepping stones. Stepping stones create functional connectivity and are especially important for birds to fly from one area to another, providing food and refuge. Depending on the feeding diets of avifauna, vegetation structure and plant species need to be carefully curated.

Although Singapore's biodiversity per unit area may be the highest in the world (Turner, 1994), it is crucial to manage the existing biodiversity-rich habitats by maintaining connectivity. Ecological connectivity through habitat corridors plays a crucial role in maintaining biodiversity. Without it, the habitats will be isolated from one another and degrade in terms of the quantity and quality of the existing flora and fauna. The Singapore River masterplan was based on the principles of habitat connectivity to connect various natural as well as novel urban habitats along its course. The river was designed with ecological principles in mind, so that it would not only serve as a conduit for people or water, but also for native wildlife. It was also designed to take into account biodiversity guidelines and considerations to support biodiversity conservation efforts. The river edge provided an opportunity to increase the percentage of natural and semi-natural areas in the urban environment. The linear and lateral habitat connections helped reduce the rate of biodiversity loss in the novel urban ecosystems. The uninterrupted vegetated river edge reduced habitat fragmentation, which enhanced ecosystem diversity.

2c. Planting strategies

Various planting strategies were developed to create distinct identities and habitats in the different zones. A thicker layer of greenery was proposed along the river edge with plants, not only to create an aesthetically improved edge, but also to provide a biodiversity-rich habitat linkage that creates lateral ecological connections with the existing urban landscapes. The planting palette was developed based on the water level, river profile, available planting space, and different activities proposed in different zones (Fig. 9).

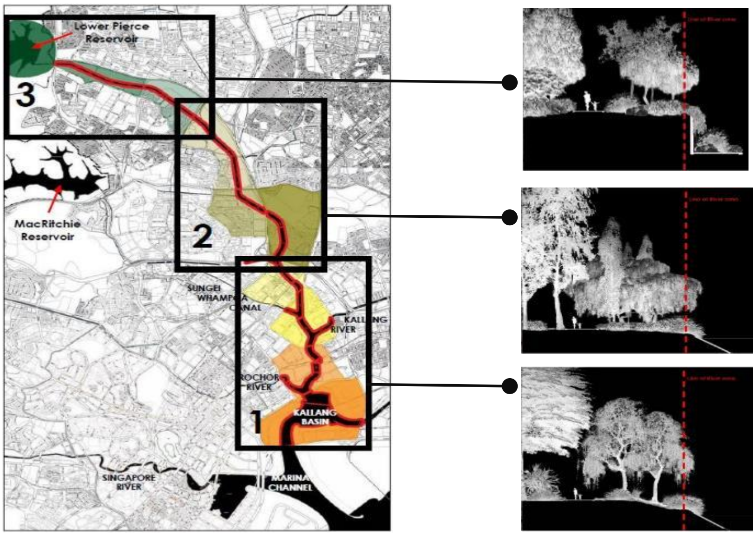


Fig. 9. Proposed planting zones. (Image credit: Damian Tang)

2d. Species selection and composition

The research shows that avifauna diversity is correlated to vegetation density and flora diversity (Briffett *et al.*, 2004). Dynamic variations in the water levels and vegetation compositions created suitable microclimates for diverse flora and fauna values. Native and fauna-attracting species were preferred over only aesthetically appealing species. The proposed habitat recreation and connection aimed to achieve the objectives of the "Singapore Index on Cities' Biodiversity (please refer to Chapter 23). Riverine vegetation structure was designed to attract birds and wildlife while still making it aesthetically attractive to the people (Fig. 10). Tree species were planted in layers to attract bird species (Fig. 11). Combinations of diverse plant species were proposed to enhance flora and fauna diversity and various habitats were proposed to create suitable microclimates for the growth of natural ecosystems.

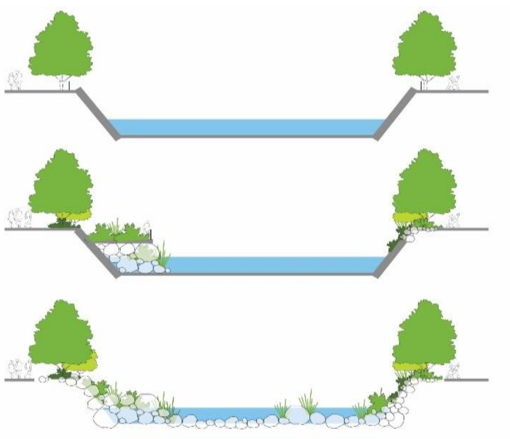


Fig. 10. Transformation of river banks from concrete bank to natural bank. (Image credit: Mayura Patil)

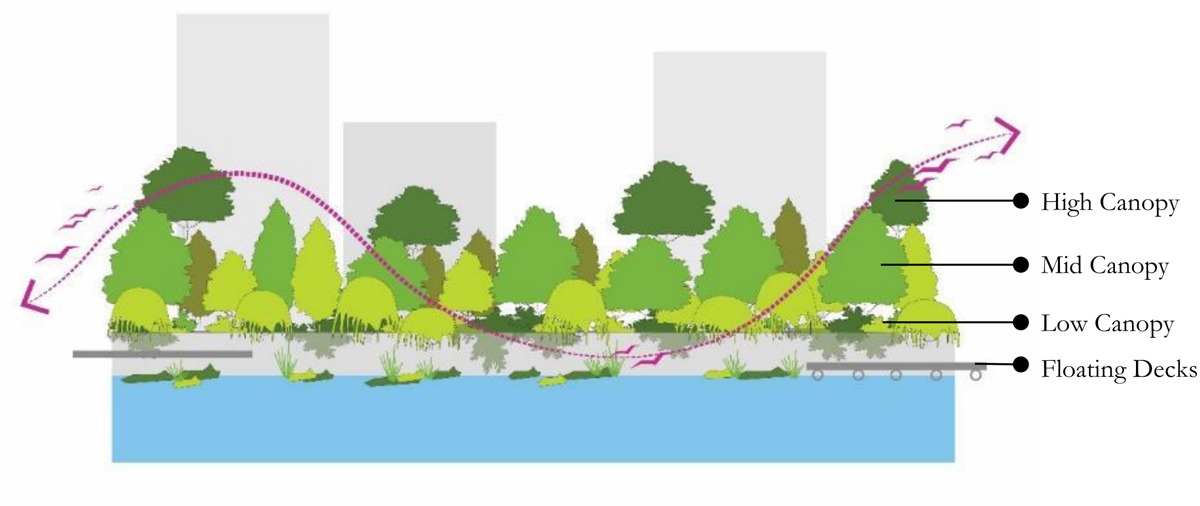


Fig. 11. Conceptual riverine planting scheme. (Image credit: Mayura Patil)

Core of the inter-agency exchange

Biodiversity enhancement or habitat restoration, which are concepts that landscape architects regularly work with, may not be familiar to most engineers. As such, the landscape architects from NParks and civil engineers from PUB needed to know each other's strengths, while aiding the understanding of terminology often used in their respective professions.

3a. Understanding requirements of other agencies

PUB has been around for more than half a century, providing Singapore with effective drainage systems, and continuously making improvements to alleviate any flash flood situations. It was important to know the priorities of PUB and the civil engineers' key technical considerations when dealing with the waterways and waterbodies. For many years, the concrete channels have been highly effective in channelling stormwater discharge during rainy weathers. The utilitarian design has specific requirements and calculations undertaken by the engineers to ensure the performance of these channels. Therefore, when designing waterways under PUB ABC Waters programme, one needs to understand the three key aspects of stormwater discharge in a channel:

I. **Hydrological analysis:** PUB takes multiple parameters in consideration while designing effective drainage systems. The first step to design drainage is to determine the catchment area that will be served by the drainage. The size as well as the type of existing and future development on the catchment area is also analysed before designing the drainage system. Based on the rainfall data, the hydrological analysis also estimates peak runoff generated from the related catchments.

II. **Hydraulic design:** The hydraulic design of the drainage system is a result of multiple factors. The design involves the calculation of developed runoff coefficients and peak runoff rates. Maximum allowable peak discharge is calculated to withstand the "1-in-50 years" storm event. The profile of the canal is also determined by the hydraulic capacity as well as the immediate surrounding of the drains.

III. **Maintenance:** The drainage maintenance regime by PUB required a 3-metre clearance for vehicular maintenance buffer on one side or both side of the drain depending on the technical and spatial constraints. The maintenance regime was rethought for the naturalised canal at Bishan-Ang Mo Kio Park. The new maintenance guidelines initiated a maintenance regime that suited the ecological and aesthetical needs of the landscape along the PUB drains.

Engineers may have a limited understanding of greenery, in terms of plants that form vegetation to create landscapes. However, the landscape architects select plants in terms of their ecological, functional, and aesthetic purposes, and create designs with those considerations in mind. Such differences in perspectives meant that during the inter-agency exchange, the scientific reasoning behind the landscape designs needed to be broken down to the civil engineers, so that the ecological outcomes could be achieved without obstructing technical requirements.

3b. Simplifying complex ideas

A master plan of this scale was expected to have ecological, hydrological as well as social components, and required inputs from experts from various agencies. With such varied considerations and different viewpoints needed, it was important that everyone understood each other's expectations better and communicating their knowledge and ideas in a simplified manner. For instance, landscape architects would need to explain how to create the river as a habitat corridor that connected habitat patches structurally and connected smaller stepping stones functionally.

3c. Performance based landscape

To design an effective drain, the engineers needed to perform various calculations considering various factors such as channel surface irregularity, channel shape variation, obstructions, type and density of vegetation, and degree of meandering (Cowan, 1956). Layers of vegetation were added on the river profile to naturalise the concrete canal. For an effective hydraulic performance of the waterway, the engineers considered the organic nature of plants, which varied in shape, size, texture, and growth rate. Hence, they used a roughness coefficient in the required calculations that took into account the changed texture on the canal profile. Thus, for an effective green-blue infrastructure, the designers had to take a note of the density, type of vegetation proposed on the river edges as well as the shape of the river flow.

3d. Involving external consultants

It was important to understand the strengths and gaps of the project team. As the grand plan for Bishan-Ang Mo Kio Park was the first-of-its-kind large-scale project, PUB engaged German landscape consultant Atelier Dreiseitl (now called Henning Larsen) who specialised in projects of similar type and scale. The consultant helped the agencies to deliver a complex modelling of the meandering Kallang River with vegetation integrated with the park. It required precise calculations to meet the capacity and hydraulics requirements from PUB, while maintaining the vision of a riverine flood plain with lush greenery.

Demonstration phase

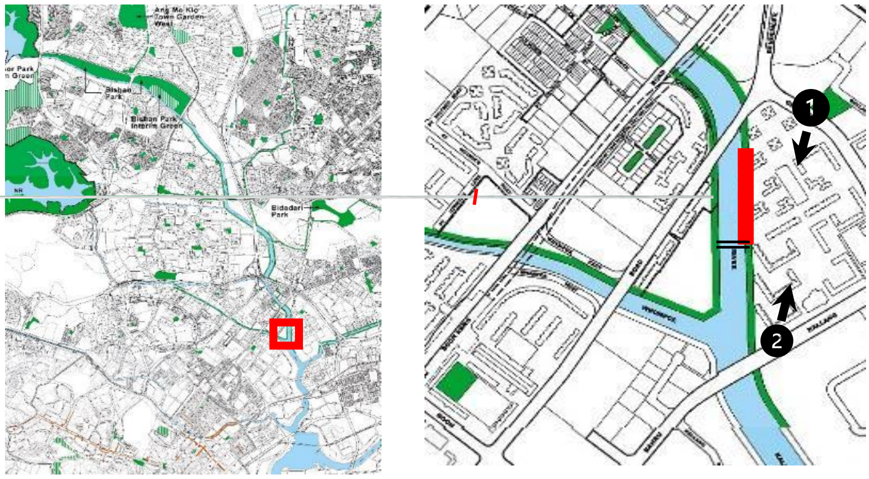
4a. Kolam Ayer

The Kolam Ayer project proved to be a great learning endeavour to successfully kickstart the ABC Waters revitalisation project for Kallang River. The demonstration phase of the ABC Waters Programme officially opened in Kolam Ayer in 2008.

The result of effective collaboration between multiple agencies as well as the local residential communities, the project sought to create an interconnected network of habitats that formed a unified ecosystem, resulting in the following:

- Park connectors along the river stretch were developed to create an uninterrupted linear link to physically connect the city to the river.
- Lateral connections were established through extending the ecosystems to the adjacent neighbourhoods.
- The proposed planting design supported the wide river profile and softened the existing edge.
- New recreational spaces were introduced to better use the under-utilised spaces along the river (Fig. 12–14).

- The activities proposed did not only establish visual connection between the users and the water, but also encouraged them to interact with water via play or exercise.
- The novel ecosystem created at the river edge also extended to the surrounding residential areas in the form of community gardens.
- From aquatic plants at the river edge, to ornamental plants along the riverside paths, the ecological network weaved in the residential areas by the means of small-scale community gardens of edible plants (Fig. 15–17).
- This network of landscaped areas encouraged public to own the new spaces and become an integral part of the project.
- Wildlife like herons, egrets, the Collared Kingfisher, and butterflies returned to the site (Fig. 18).



Figs. 12. Location of Kolam Ayer Demonstration project, 2005. (Photo credit: Damian Tang)

Before development:

Figs. 13. (A) Site 1 before enhancement; (B) Artist's impression of boardwalks and viewing decks. (Photo credit: Damian Tang)

Figs. 14. (A) Site 2 before enhancement; (B) Artist's impression of interactive water play area. (Photo credit: Damian Tang)

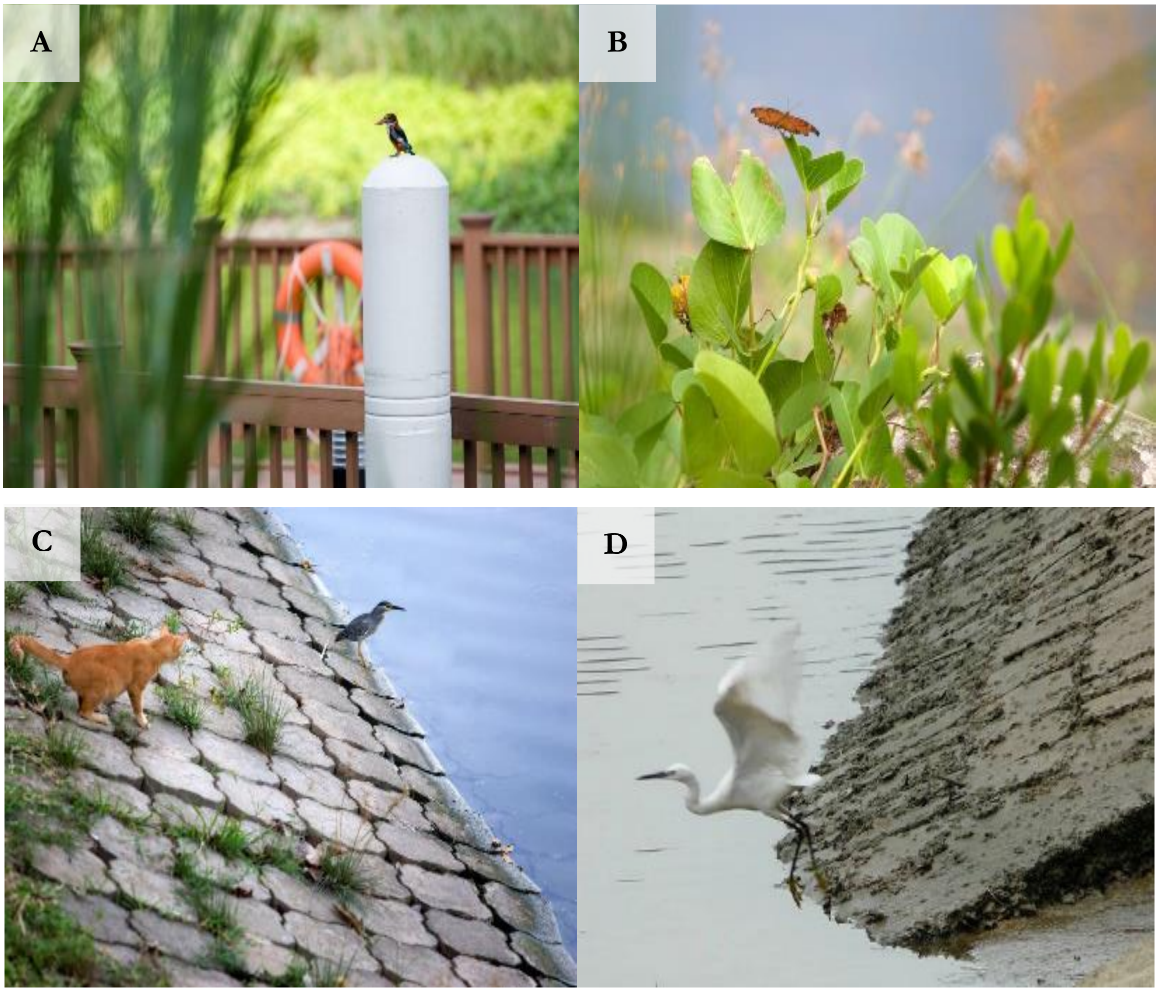
After development:

Figs. 15. (A) A view of the naturalised river edge; (B) water interactive exercise equipment at Kolam Ayer. (Photo credit: Damian Tang)

Figs. 16. (A) Water interactive play for the young and elderly; (B) viewing decks at Kolam Ayer. (Photo credit: Damian Tang)

Figs. 17. (A) Spaces along the river edge designed to encourage communal activities and (B) community gardens along the river at Kolam Ayer. (Photo credit: Damian Tang)

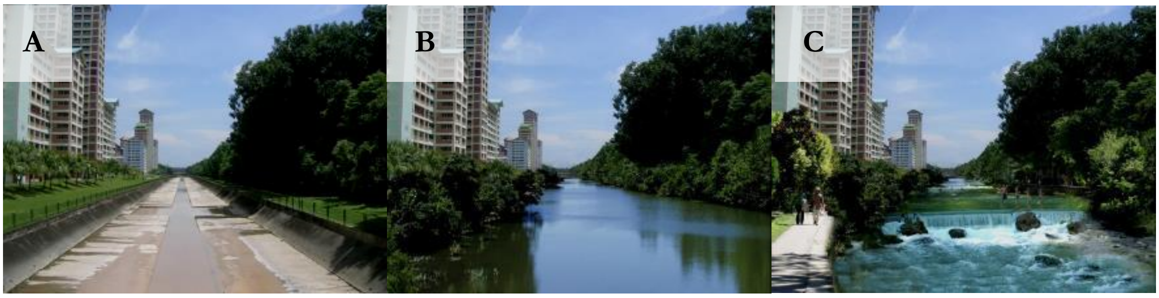
Biodiversity spotted after completion of the project:



Figs. 18. (A) Blue-eared Kingfisher (*Alcedo meninting*); (B) Tawny Coster (*Acraea terpsicore*); (C) Striated Heron (*Butorides striata*); (D) Little Egret (*Egretta garzetta*). (Photo credit: Damian Tang)

4b. Rejuvenating Bishan-Ang Mo Kio Park

The visionary images of Kallang River illustrated the possibilities of waterways and waterbodies that could be transformed in different phases (Fig. 19). The idea behind the integrated landscape design for Bishan-Ang Mo Kio Park arose from the broader Kallang River master plan, where certain nodes were identified for potential rejuvenation. The transformation of Bishan Park (with its concrete canal) to the biodiversity-rich riverine Bishan-Ang Mo Kio Park became clearly visible from the image documentation, a vision that we wish to bring to other waterways in Singapore. The Bishan Ang Mo Kio Park would later win multiple awards including the prestigious 'Landscape of the Year' award at the World Architecture Festival, 2012.



Figs. 19. (A) Concrete canal in Bishan Park, 2012; (B) 'Naturalising river edge' artist's impression of Bishan-Ang Mo Kio Park; (C) 'Vision for our river' artist's impression of Bishan-Ang Mo Kio Park. (Photo credit: Damian Tang)

The naturalised river in Bishan-Ang Mo Kio Park has created community spaces and diverse habitats for several fauna species. The park's biodiversity has increased over the years, including 150 species of wildflowers, up to 155 species of birds (data provided by eBird, www.ebird.org, and created on 7 June 2023), 38 species of dragonflies and damselflies, 47 species of butterflies, four species of mammals, and eight aquatic species (Hwang *et al.*, 2020). Some of the fauna species observed at the park are listed in the Annex (National Parks Board, 2020).

Learning points

For projects that do not have precedents in Singapore, it is important to learn from other case studies that are of similar scale and type, involving a similar-sized location and similar design fundamentals. While studying other cases, it is also important to collect and analyse information about constraints and problems faced during the realisation of the project. Designers must not forget that behind every calculation lies a performance, which is the most important factor that will determine the effectiveness of the project.

To make the landscape truly functional, planners need to develop landscape strategies beyond designated bureaucratic boundaries. Such strategies can be formulated based on learning from demonstration sites and the results of interventions tested on those sites. When undertaking such large-scale projects, multiple agencies need to work together and leverage each other's expertise, while facilitating communication within the large team by simplifying complex ideas.

At the same time, it is important to recognise the gaps in the team's expertise and strengths, and getting other field experts, such as external consultants, involved at the right stage of the project.

Ultimately, all agencies and other consultants will need to manage differences and trade-offs while keeping the bigger picture of achieving highly functional ecologies in mind.

In conclusion, Singapore's approach to urban green spaces and biodiversity conservation involves a combination of preserving natural areas, creating green spaces within the city, and restoring degraded ecosystems. These efforts have not only improved the overall liveability of the city but also provided opportunities for nature exploration, environmental education, and ecological connectivity. By recognising the value of green spaces and implementing sustainable practices, Singapore continues to set an example for other cities around the world in balancing urban development with environmental conservation.

Acknowledgements
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Annex: List of fauna observed at Bishan-Ang Mo Kio Park after the completion of the project.

Birds

	Common name	Scientific name
1	African Grey Parrot	*Psittacus erithacus*
2	Arctic Warbler	*Phylloscopus borealis*
3	Ashy Minivet	*Pericrocotus divaricatus*
4	Asian Brown Flycatcher	*Muscicapa dauurica*
5	Asian Glossy Starling	*Aplonis panayensis*
6	Asian Koel	*Eudynamys scolopacea*
7	Barn Swallow	*Hirundo rustica*
8	Black Bittern	*Ixobrychus flavicollis*
9	Black Crowned Night Heron	*Nycticorax nycticorax*
10	Black-headed Munia	*Lonchura malacca*
11	Black-naped Oriole	*Oriolus chinensis*
12	Blue tailed Bee Eater	*Merops viridis*
13	Blue Throated Bee Eater	*Merops philippinus*
14	Blue-Crown Hanging Parrot	*Loriculus galgulus*
15	Brahminy Kite	*Haliastur indus*
16	Bronze Mannikin	*Lonchura cucullata*
17	Brown Shrike	*Lanius cristatus*
18	Brown-throated Sunbird	*Anthreptes malacensis*
19	Cattle Egret	*Bubulcus ibis*
20	Changeable Hawk Eagle	*Spizaetus cirrhatus*
21	Chinese Pond Heron	*Ardeola bacchus winter*
22	Collared Kingfisher	*Todiramphus chloris*
23	Common Flameback	*Dinopium javanense*
24	Common Iora	*Aegithina tiphia*
25	Common Kingfisher	*Alcedo atthis*
26	Common Myna	*Acridotheres tristis*
27	Common Sandpiper	*Actitis hypoleucos*

Birds ***(Cont'd)***

28	Common Tailorbird	*Orthotomus sutorius*
29	Coppersmith Barbet	*Psilopogon haemacephala*
30	Crested Goshawk	*Accipiter trivirgatus*
31	Crested Honey Buzzard	*Pernis ptilorhynchus*
32	Crimson Rumped Waxbill	*Estrilda rhodopyga*
33	Crimson Sunbird	*Aethopyga siparaja*
34	Dollarbird	*Eyrystimas orientalis*
35	Eurasion Tree Sparrow	*Passer montanus*
36	Germain's Swiftlet	*Aerodramus germani*
37	Golden-bellied Gerygone	*Gerygone sulphurea*
38	Grey headed Swamphen	*Porphyrio poliocephalus*
39	Grey Heron	*Ardea cinerea*
40	Grey Rumped Treeswift	*Hemiprocne longipennis*
41	Hill Mynah	*Gracula religiosa*
42	House Crow	*Corvus splendens*
43	Intermediate Egret	*Egretta intermedia*
44	Japanese Sparrowhawk	*Accipiter gularis*
45	Javan Myna	*Acridotheres javanicus*
46	Javan Pond Heron	*Ardeola speciosa*
47	Large-Billed Crow	*Corvus macrorhynchos*
48	Little Bronze Cuckoo	*Chrysococcyx minutillus*
49	Little Egret	*Egretta garzetta*
50	Long-tailed Parakeet	*Psittacula longicauda*
51	Long Tailed Shrike	*Lanius schach*
52	Lutino Lovebird	*Agapornis roseicollis var.*
53	Olive Backed Sunbird	*Nectarinia jugularis*
54	Orange Cheeked Waxbills	*Estrilda melpoda*
55	Oriental Magpie Robin	*Copsychus saularis*
56	Oriental Pied Hornbill	*Anthracoceros albirostris*
57	Oriental Reed Warbler	*Acrocephalus orientalis*

Birds ***(Cont'd)***

58	Oriental White-eye	*Zosterops palpebrosus*
59	Pacific Golden Plover	*Pluvialis fulva*
60	Pacific Swallow	*Hirundo tahitica*
61	Paddyfield Pippit	*Anthus rufulus*
62	Pied Fantail	*Rhipidura javanica*
63	Pied Triller	*Lalage nigra*
64	Pink-necked Green Pigeon	*Treron vernans*
65	Purple Heron	*Ardea purpurea*
66	Rainbow Lorikeets	*Trichoglossus moluccanus*
67	Red Junglefowl	*Gallus gallus*
68	Red Turtle Dove	*Streptopelia tranquebarica*
69	Red-breasted Parakeet	*Psittacula alexandri*
70	Red-Whiskered Bulbul	*Pycnonotus jocosus*
71	Rock Pigeon	*Columba livia*
72	Rose-ringed Parakeet	*Psittacula krameri*
73	Scaly-breasted Munia	*Lonchura punctulata*
74	Scarlet Minivet	*Pericrocotus speciosus*
75	Scarlet-backed Flower Pecker	*Dicaeum cruentatum*
76	Slaty-breasted Rail	*Gallirallus striatus*
77	Spotted Dove	*Streptopelia chinensis*
78	Spotted Wood Owl	*Strix seloputo*
79	Stork-Billed Kingfisher	*Pelargopsis capensis*
80	Striated Heron	*Butorides striatus*
81	Striped Tit Babbler	*Macronus gularis*
82	Sunda Pygmy Woodpecker	*Dendrocopus moluccensis*
83	Swinhoe's White-eye	*Zosterops simplex*
84	Tiger Shrike	*Lanius tigrinus*
85	White Breasted Waterhen	*Amaurornis phoenicurus*
86	White Headed Munia	*Lonchura maja*
87	White Wagtail	*Motacilla alba*

Birds ***(Cont'd)***

88	White-bellied Sea Eagle	*Haliaeetus leucogaster*
89	White-throated Kingfisher	*Halcyon smyrnensis*
90	Yellow Bittern	*Ixobryshus sinensis*
91	Yellow-bellied Prinia	*Prinia flaviventris*
92	Yellow-fronted Canary	*Serinus mozambicus*
93	Yellow-vented Bulbul	*Pycnonotus goiavier*
94	Zanzibar Red Bishop	*Euplectes nigroventris*
95	Zebra Dove	*Geopelia striata*

Dragonflies and damselflies

	Common name	**Scientific name**
1	Blue Adjutant	*Aethriamanta aethra*
2	Blue Dasher	*Brachydiplax chalybea*
3	Blue Percher	*Diplacodes trivialis*
4	Blue Sprite	*Pseudagrion microcephalum*
5	Coastal Glider	*Macrodiplax cora*
6	Common Amberwing	*Brachythemis contaminata*
7	Common Blue Skimmer	*Orthetrum glaucum*
8	Common Bluetail	*Ischnura senegalensis*
9	Common Chaser	*Potamarcha congener*
10	Common Flangetail	*Ictinogomphus decoratus*
11	Common Parasol	*Neurothemis fluctuans*
12	Common Redbolt	*Rhodothemis rufa*
13	Common Scarlet	*Crocothemis servilia*
14	Crimson Dropwing	*Trithemis aurora*
15	Emperor	*Anax guttatus*
16	Fiery Coraltail	*Ceriagrion chaoi*
17	Grenadier	*Agrionoptera insignis*
18	Indigo Dropwing	*Trithemis festiva*
19	Look-alike Sprite	*Pseudagrion australasiae*

Dragonflies and damselflies ***(Cont'd)***

20	Ornate Coraltail	*Ceriagrion cerinorubellum*
21	Pond Adjudant	*Aethriamanta gracilis*
22	Saddlebag Glider	*Tramea transmarina*
23	Sapphire Flutterer	*Rhyothemis triangularis*
24	Scarlet Adjudant	*Aethriamanta brevipennis*
25	Scarlet Basker	*Urothemis signata*
26	Scarlet Grenadier	*Lathrecista asiatica*
27	Scarlet Skimmer	*Orthetrum testaceum*
28	Slender Duskdarter	*Zyxomma petiolatum*
29	Spine-tufted Skimmer	*Orthetrum chrysis*
30	Trumpet Tail	*Acisoma panorpoides*
31	Variable Sprite	*Argiocnemis rubescens*
32	Variable Wisp	*Agriocnemis femina*
33	Variegated Green Skimmer	*Orthetrum sabina*
34	Wandering Glider	*Pantala flavescens*
35	Water Monarch	*Hydrobasileus croceus*
36	White-barred Duskhawk	*Tholymis tillargis*
37	Yellow-barred Flutterer	*Rhyothemis phyllis*
38		*Aethriamanta* species

Butterflies and moths

	Common name	**Scientific name**
1	Atlas Moth	*Attacus atlas*
2	Autumn Leaf	*Doleshallia bisaltide bisaltide*
3	Black Vein Tiger	*Danaus melanippus hegesippus*
4	Blue Glassy Tiger	*Ideopsis vulgaris macrina*
5	Blue Pansy	*Junonia orithya wallacei*
6	Bush Hopper	*Ampittia dioscorides camertes*
7	Chocolate Grass Yellow	*Eurema sari sodalis*
8	Chocolate Pansy	*Junonia hedonia ida*

Butterflies and moths ***(Cont'd)***

9	Ciliate Blue	*Anthene emolus goberus*
10	Common Bluebottle	*Graphium sarpedon lucatius*
11	Common Grass Yellow	*Eurema hecabe contubernalis*
12	Common Mime	*Papilio clytia clytia*
13	Common Mormon	*Papilio polytes romulus*
14	Common Palmfly	*Elymnias hypermnestra agina*
15	Common Rose	*Pachiliopta aristolochiae asteris*
16	Common Sailor	*Neptis hylas*
17	Common Tiger	*Danaus genutia genutia*
18	Common Tit	*Hypolycaena erylus teatus*
19	Contiguous Swift	*Polytremis lubricans lubricans*
20	Cycad Blue	*Chilades pandava*
21	Dark Grassy Tiger	*Parantica algeoides algeoides*
22	Green Baron	*Euthalia adonia pinwillia*
23	Jacintha Eggfly	*Hypolimnas bolina jacintha*
24	Julia Heliconian	*Dryas iulia*
25	Lemon Emigrant	*Catopsilia pomona pomona*
26	Leopard	*Phalantha phalantha*
27	Lesser Dart	*Potanthus omaha*
28	Lesser Grass Blue	*Zizina otis lampa*
29	Lime Butterfly	*Papilio demoleus malayanus*
30	Mottled Emigrant	*Catopsilia pyranthe pyranthe*
31	Orange Emigrant	*Catopsilia scylla cornelia*
32	Painted Jezebel	*Delias hyparete metarete*
33	Pale Bob	*Suastas gremius gremius*
34	Pale Palm Dart	*Telicota colon argeus*
35	Pea Blue	*Lampides boeticus*
36	Peacock Pansy	*Junonia almana javana*
37	Peacock Royal	*Tajuria cippus maxentius*
38	Plain Tiger	*Danaus chrysippus chrysippus*

Butterflies and moths ***(Cont'd)***

39	Psyche	*Leptosia nina malayana*
40	Pygmy Grass Blue	*Zizula hylax pigmaea*
41	Short Banded Sailor	*Phaedyma columella singfa*
42	Small Branded Swift	*Pelopidas mathias mathias*
43	State Flash	*Rapala manea chozeba*
44	Striped Albatross	*Appias libythea olferna*
45	Tailed Jay	*Graphium agamemnon agamemnon*
46	Tailless Line Blue	*Prosotas dubiosa lumpura*
47	Tawny Coster	*Acraea terpsicore*

Bees and wasps

	Common name	**Scientific name**
1	Andrew's Blue-banded Digger Bee	*Amegilla andrewsi*
2	Asian Honey Bee	*Apis cerana*
3	Black Mud Wasp	*Delta emarginatum*
4	Carpenter Bee	*Xylocopa aestuens*
5	Confusing Cone-waisted Cuckoo Bee	*Coelioxys confusa*
6	Emerald Cuckoo Wasp	*Chrysis sp.*
7	Giant Honey Bee	*Apis dorsata*
8	Greater Banded Hornet	*Vespa tropica*
9	Himalayan Cloak-and-dagger Bee	*Thyreus himalayensis*
10	Lesser Banded Hornet	*Vespa affinis*
11	Pearly Banded Bee	*Nomia strigata*
12	Potter Wasp	*Rhynchium haemorrhoidale*
13	Shadow-winged Resin Bee	*Megachile umbripennis*
14	Wide-footed Carpenter Bee	*Xylocopa latipes*

CHAPTER 10

Kranji Marshes – Restoration of Marshes and Wetlands

Chua Yen Kheng, David Li, How Choon Beng & Yang Shufen

Introduction

The damming of Kranji River in the 1970s to create a reservoir led to the loss of mangroves and prevented the natural discharge of sediment into the Johor Straits. Upstream, however, this development resulted in the formation of rare freshwater marsh habitats, which very soon attracted a variety of marsh birds such as herons, bitterns and rails. Over time, the build-up of sediment and vegetation overgrowth threatened to turn portions of the marshes into a shrub habitat. Exotic water plants also invaded the open water areas, further reducing suitable habitats for marsh birds.

Between 2008 to 2014, under the Active, Beautiful and Clean Waters (ABC Waters) programme of PUB, the Nature Society (Singapore) (NSS), implemented a habitat management plan to maintain a good balance between open water and vegetated areas for the marsh birds to use. The National Parks Board (NParks) and the Urban Redevelopment Authority (URA) started working closely with PUB and NSS in 2011 to enhance the marshes so that the public can enjoy its flora and fauna. The enhancement was completed at the end of 2015, and the 56-hectare Kranji Marshes was officially opened on 1 February 2016.

Objective of the habitat enhancement

The main objective of the habitat enhancement efforts carried out at Kranji Marshes was to create aquatic areas with different water levels, plant composition and density to encourage a diverse range of wetland-dependent birds and other wildlife to thrive in the marsh habitat. Improvement works done included:

- Removal of overgrown aquatic plants to maintain a balance of open water surface and aquatic vegetation to provide waterbirds like Rails and Crakes that prefer dense aquatic plants to hide and Lesser Whistling Duck (*Dendrocygna javanica*) that prefers open water bodies to swim with safe feeding grounds;

- Dredging of built-up sediments in ponds, which were used to create island havens that offered more feeding and resting grounds for marsh birds;

- Addition of a variety of aquatic plants consisting of emergents (plants that are rooted at the bottom of wetlands but their leaves and stems extend out of the water) which provided protective covers, and submergents (plants that are rooted at the bottom of wetlands with most of their structures below the water surface) which provided food for marsh birds, as well as habitats for invertebrates, which were in turn eaten by birds;

- Increasing the flora diversity by planting species of native plants that provided food, protective cover and nesting materials for a range of forest-dependent and grassland birds;

- Contouring the banks of ponds to create shallow-water feeding grounds for birds such as the Common Snipe (*Gallinago gallinago*) and Greater Painted-snipe (*Rostratula benghalensis*);

- Creation of an island with stony surfaces favoured by Red-wattled Lapwings (*Vanellus indicus*) as nesting grounds; and

- Installation of perches in open water areas for birds such as raptors and kingfishers.

State of the biodiversity of Kranji Marshes

Today, Kranji Marshes (Fig. 1) is a rare habitat that supports a variety of unique wildlife. Together with Sungei Buloh Wetland Reserve (SBWR) and Mandai Mangrove and Mudflat (MMM), it forms an important network of core wetland habitats in the Kranji area for the conservation of biodiversity, especially birds (Appendix 1). SBWR and MMM are known for shorebirds that use coastal wetlands. Kranji Marshes complements SBWR and MMM with freshwater wetland habitats. These core wetlands, with interlinking ecological corridors and nature parks, form the Sungei Buloh Nature Park Network (SBNPN) which was announced in 2020. The SBNPN strengthens the conservation of wetland biodiversity in western part of Singapore by conserving up to 400 hectares which is three times the original size of the legally gazetted SBWR.

Fig. 1. Kranji Marshes with its iconic Raptor Tower.

Significant marsh bird species that reside here include the Grey-headed Swamphen (*Porphyrio poliocephalus*), Lesser Whistling Duck (*Dendrocygna javanica*) (Fig. 2) and the Red-wattled Lapwing (*Vanellus indicus*) (Fig. 3). A Booted Warbler (*Iduna caligata*), a new bird record for Singapore, was seen at Kranji Marshes from December 2017 until March 2018.

Fig. 2. A flock of Lesser Whistling Duck (*Dendrocygna javanica*) is seen in Kranji Marshes.

Fig. 3. A deceit of Red-wattled Lapwing (*Vanellus indicus*) is sighted in Kranji Marshes.

Regular bird surveys conducted after the habitat enhancement efforts by NParks and NSS revealed that marsh birds were actively using and feeding in the newly enhanced marsh niches. However, if not regularly maintained, the niches quickly became overgrown with vegetation and the birds would no longer be observed there. Such prolific green growth not only reduced the open water surfaces or wet ground surfaces available for water birds to feed directly, but might also obstruct the birds' lines of sight for predators, making them feel unsafe to hang around in such areas to feed or rest. The challenge in maintaining Kranji Marshes as a home for resident marsh birds, as well as a pit stop for some migratory bird species, therefore, depended on careful planning and implementation of habitat maintenance regime. These involved identifying vegetation management zones, prescribing the right maintenance frequency to each zone, monitoring the re-growth of unwanted vegetation and reviewing the weeding method and maintenance approach regularly.

In addition, new flora and faunal species of conservation significance had also been recorded in Kranji Marshes. In 2019, the Common Reed (*Phragmites karka*), which is uncommon, was surprisingly sighted flourishing in Kranji Marshes. It had not been seen for more than 140 years, since it was last collected by Henry Ridley. It has since been collected and propagated in NParks' Native Plant Centre, and introduced to other suitable wetlands in Singapore.

A new species of Dolicopodidae, the long-legged fly *Gymnopternus ghufrani* sp. nov, was found in Kranji Marshes in 2020. It was named after SBWR staff Ghufran who helped extensively in the surveys with lead researchers.

In 2022, a camera trap captured the presence of a Leopard Cat (*Prionailurus bengalensis*) during a collaboration study involving the Nanyang Technological University and NParks. In the same year, a new dragonfly record, *Heliaschna simplicia* for Singapore was also sighted within the Core Conservation Area by our bird census NSS partner, underscoring two critical points: 1) the importance of expert citizen scientists partnerships and 2) the sensitive balance between nature recreation access and conservation.

Conclusions and lessons learnt

The total area of Kranji Marshes, one of the largest remaining freshwater marshes in Singapore, amounts to 56 hectares. Numerous ponds are found in Kranji Marshes and they require constant, careful maintenance due to the aggressive nature of the exotic freshwater weeds such as Water Hyacinth. This presents challenges in addition to resources required to achieve the desired conservation outcome. Regular maintenance can be affected in an unforeseen event, such as the COVID-19 outbreak, that resulted in disruption of resources in the landscape industry, staff and volunteers.

Fortunately, the figures compiled on 30 June 2023 (Appendix 1) tell a compelling story. The 281 bird species sighted in SBWR amounts to 67% of the total number of bird species recorded in Singapore, while 235 bird species can be found in Kranji Marshes, amounting to 56% of Singapore's total. SBNPN is home to 298 bird species, which is 71% of the national bird record. Earlier examples of sightings showed that the rich biodiversity of the area is not limited to birds, as unique wetland plants, mammals such as the Leopard Cat, and insects such as dragonflies and long-legged flies continue to be recorded and thriving.

The ecological rationale for a conservation strategy in creating SBNPN, which comprises the core complementary habitats of SBWR, Kranji Marshes and MMM that are complemented by buffers and eco-corridors, is evidently beneficial to resident and migratory wetland birds and other species. With global climate change and developments, the safe-guarding of these habitats and ensuring ecological connectivity are of national as well as regional and international significance.

Appendix 1: Birds recorded at Sungei Buloh Wetland Reserve, Kranji Marshes and Sungei Buloh Nature Park Network as of 30 June 2023 as compared to all birds recorded in Singapore.

Number	Common Name	Scientific Name	Migration Status	Global Conservation Status (2023)	National Conservation Status (2021)	SBWR	KM	SBNPN
1	Wandering Whistling Duck	*Dendrocygna arcuata*	R	LC	NA	**1**	**1**	**1**
2	Lesser Whistling Duck	*Dendrocygna javanica*	R	LC	EN	**1**	**1**	**1**
3	Cotton Pygmy Goose	*Nettapus coromandelianus*	R	LC	CR		**1**	**1**
4	Garganey	*Anas querquedula*	M	LC	VU	**1**		**1**
5	Northern Shoveler	*Anas clypeata*	M	LC	NE	**1**		**1**
6	Gadwall	*Anas strepera*	M	LC	NE	**1**		**1**
7	Eurasian Wigeon	*Anas penelope*	M	LC	NE	**1**	**1**	**1**
8	Northern Pintail	*Anas acuta*	M	LC	NE	**1**		**1**
9	Tufted Duck	*Aythya fuligula*	M	LC	NE			
10	Red Junglefowl	*Gallus gallus*	R	LC	NT	**1**	**1**	**1**
11	King Quail	*Excalfactoria chinensis*	R	LC	LC	**1**	**1**	**1**
12	Malaysian Eared Nightjar	*Lyncornis temminckii*	R	LC	CR			
13	Grey Nightjar	*Caprimulgus jotaka*	M	LC	LC			
14	Large-tailed Nightjar	*Caprimulgus macrurus*	R	LC	LC	**1**	**1**	**1**
15	Savanna Nightjar	*Caprimulgus affinis*	R	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

16	Grey-rumped Treeswift	*Hemiprocne longipennis*	R	LC	NT	**1**	**1**	**1**
17	Whiskered Treeswift	*Hemiprocne comata*	NBV	LC	LC			
18	Plume-toed Swiftlet	*Collocalia affinis*	R	NE	VU			
19	Black-nest Swiftlet	*Aerodramus maximus*	R	LC	NT	**1**	**1**	**1**
20	Germain's Swiftlet	*Aerodramus germani*	R	LC	LC	**1**	**1**	**1**
21	Silver-rumped Needletail	*Rhaphidura leucopygialis*	NBV	LC	LC			
22	White-throated Needletail	*Hirundapus caudacutus*	M	LC	LC			
23	Silver-backed Needletail	*Hirundapus cochinchinensis*	M	LC	LC			
24	Brown-backed Needletail	*Hirundapus giganteus*	M	LC	LC		**1**	**1**
25	Asian Palm Swift	*Cypsiurus balasiensis*	R	LC	NT	**1**	**1**	**1**
26	Common Swift	*Apus apus*	M	LC	NE			
27	Pacific Swift	*Apus pacificus*	M	LC	LC	**1**	**1**	**1**
28	House Swift	*Apus nipalensis*	R	LC	VU	**1**	**1**	**1**
29	Greater Coucal	*Centropus sinensis*	R	LC	NT	**1**	**1**	**1**
30	Lesser Coucal	*Centropus bengalensis*	R	LC	LC	**1**	**1**	**1**
31	Chestnut-bellied Malkoha	*Phaenicophaeus sumatranus*	R	NT	NT	**1**	**1**	**1**
32	Chestnut-winged Cuckoo	*Clamator coromandus*	M	LC	LC	**1**	**1**	**1**
33	Jacobin Cuckoo	*Clamator jacobinus*	M	LC	NE			
34	Asian Koel	*Eudynamys scolopaceus*	R	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

35	Asian Emerald Cuckoo	*Chrysococcyx maculatus*	M	LC	NE			
36	Violet Cuckoo	*Chrysococcyx xanthorhynchus*	R/M	LC	n-T	**1**	**1**	**1**
37	Horsfield's Bronze Cuckoo	*Chrysococcyx basalis*	M	LC	LC		**1**	**1**
38	Little Bronze Cuckoo	*Chrysococcyx minutillus*	R	LC	LC	**1**	**1**	**1**
39	Banded Bay Cuckoo	*Cacomantis sonneratii*	R	LC	LC	**1**	**1**	**1**
40	Plaintive Cuckoo	*Cacomantis merulinus*	R	LC	LC	**1**	**1**	**1**
41	Rusty-breasted Cuckoo	*Cacomantis sepulcralis*	R	LC	NT	**1**	**1**	**1**
42	Square-tailed Drongo-Cuckoo	*Surniculus lugubris*	R/M	LC	VU	**1**	**1**	**1**
43	Large Hawk-Cuckoo	*Hierococcyx sparverioides*	M	LC	LC	**1**	**1**	**1**
44	Malaysian Hawk-Cuckoo	*Hierococcyx fugax*	NBV	LC	NT	**1**		**1**
45	Hodgson's Hawk-Cuckoo	*Hierococcyx nisicolor*	M	LC	NT	**1**	**1**	**1**
46	Indian Cuckoo	*Cuculus micropterus*	M	LC	LC	**1**	**1**	**1**
47	Himalayan Cuckoo	*Cuculus saturatus*	M	LC	LC			
48	Rock Dove	*Columba livia*	R	LC	NA	**1**	**1**	**1**
49	Oriental Turtle-dove	*Streptopelia orientalis*	M	LC	NE			
50	Red Collared Dove	*Streptopelia tranquebarica*	R	LC	NA	**1**	**1**	**1**
51	Spotted Dove	*Spilopelia chinensis*	R	LC	LC	**1**	**1**	**1**
52	Common Emerald Dove	*Chalcophaps indica*	R	LC	LC	**1**	**1**	**1**
53	Zebra Dove	*Geopelia striata*	R	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

54	Cinnamon-headed Green Pigeon	*Treron fulvicollis*	R	VU	EN	**1**		**1**
55	Little Green Pigeon	*Treron olax*	NBV	LC	CR			
56	Pink-necked Green Pigeon	*Treron vernans*	R	LC	LC	**1**	**1**	**1**
57	Orange-breasted Green Pigeon	*Treron bicinctus*	NBV	LC	LC			
58	Thick-billed Green Pigeon	*Treron curvirostra*	R	LC	VU	**1**	**1**	**1**
59	Jambu Fruit Dove	*Ptilinopus jambu*	NBV	NT	VU	**1**	**1**	**1**
60	Green Imperial Pigeon	*Ducula aenea*	R	NT	EN			
61	Mountain Imperial Pigeon	*Ducula badia*	NBV	LC	LC			
62	Pied Imperial Pigeon	*Ducula bicolor*	R	LC	DD	**1**	**1**	**1**
63	Masked Finfoot	*Heliopais personata*	M	CR	EN	**1**	**1**	**1**
64	Slaty-breasted Rail	*Gallirallus striatus*	R	LC	LC	**1**	**1**	**1**
65	Common Moorhen	*Gallinula chloropus*	R	LC	EN	**1**	**1**	**1**
66	Grey-headed Swamphen	*Porphyrio poliocephalus*	R	LC	CR	**1**	**1**	**1**
67	Ruddy-breasted Crake	*Porzana fusca*	R/M	LC	NT	**1**	**1**	**1**
68	Band-bellied Crake	*Porzana paykullii*	M	NT	NT			
69	Baillon's Crake	*Porzana pusilla*	M	LC	VU	**1**	**1**	**1**
70	Slaty-legged Crake	*Rallina eurizonoides*	M	LC	LC			
71	Red-legged Crake	*Rallina fasciata*	R/M	LC	NT	**1**	**1**	**1**
72	White-browed Crake	*Porzana cinerea*	R	LC	VU	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

73	Watercock	*Gallicrex cinerea*	M	LC	EN	**1**	**1**	**1**
74	White-breasted Waterhen	*Amaurornis phoenicurus*	R/M	LC	LC	**1**	**1**	**1**
75	Little Grebe	*Tachybaptus ruficollis*	R	LC	CR			
76	Barred Buttonquail	*Turnix suscitator*	R	LC	LC	**1**	**1**	**1**
77	Beach Stone-curlew	*Esacus magnirostris*	R	NT	CR			
78	Black-winged Stilt	*Himantopus himantopus*	M	LC	DD	**1**	**1**	**1**
79	Pied Stilt	*Himantopus leucocephalus*	MB	LC	DD			
80	Grey-headed Lapwing	*Vanellus cinereus*	M	LC	NE	**1**	**1**	**1**
81	Red-wattled Lapwing	*Vanellus indicus*	R	LC	NT	**1**	**1**	**1**
82	Masked Lapwing	*Vanellus miles*	R	LC	NA		**1**	1
83	Pacific Golden Plover	*Pluvialis fulva*	M	LC	VU	**1**	**1**	**1**
84	Grey Plover	*Pluvialis squatarola*	M	LC	NT	**1**		**1**
85	Common Ringed Plover	*Charadrius hiaticula*	M	LC	NE	**1**		**1**
86	Little Ringed Plover	*Charadrius dubius*	M	LC	EN	**1**	**1**	**1**
87	Kentish Plover	*Charadrius alexandrinus*	M	LC	EN	**1**		**1**
88	White-faced Plover	*Charadrius dealbatus*	M	DD	EN			
89	Javan Plover	*Charadrius javanicus*	R/NBV	LC	NE			
90	Malaysian Plover	*Charadrius peronii*	R	NT	CR			
91	Lesser Sand Plover	*Charadrius mongolus*	M	LC	NT	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

92	Greater Sand Plover	*Charadrius leschenaultii*	M	LC	NT	**1**		**1**
93	Oriental Plover	*Charadrius veredus*	M	LC	LC			
94	Greater Painted-snipe	*Rostratula benghalensis*	R	LC	EN	**1**	**1**	**1**
95	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	M	LC	VU	**1**	**1**	**1**
96	Eurasian Whimbrel	*Numenius phaeopus*	M	LC	NT	**1**	**1**	**1**
97	Little Curlew	*Numenius minutus*	M	LC	NE	**1**		**1**
98	Far Eastern Curlew	*Numenius madagascariensis*	M	EN	EN	**1**		**1**
99	Eurasian Curlew	*Numenius arquata*	M	NT	EN	**1**		**1**
100	Bar-tailed Godwit	*Limosa lapponica*	M	NT	VU	**1**		**1**
101	Black-tailed Godwit	*Limosa limosa*	M	NT	CR	**1**	**1**	**1**
102	Ruddy Turnstone	*Arenaria interpres*	M	LC	EN	**1**	**1**	**1**
103	Great Knot	*Calidris tenuirostris*	M	EN	EN	**1**		**1**
104	Red Knot	*Calidris canutus*	M	NT	NT	**1**		**1**
105	Ruff	*Calidris pugnax*	M	LC	LC	**1**		**1**
106	Broad-billed Sandpiper	*Calidris falcinellus*	M	LC	VU	**1**		**1**
107	Sharp-tailed Sandpiper	*Calidris acuminata*	M	VU	NE			
108	Curlew Sandpiper	*Calidris ferruginea*	M	NT	EN	**1**	**1**	**1**
109	Long-toed Stint	*Calidris subminuta*	M	LC	EN	**1**	**1**	**1**
110	Spoon-billed Sandpiper	*Calidris pygmeus*	M	CR	CR			

Appendix 1 *(Cont'd)*

111	Red-necked Stint	*Calidris ruficollis*	M	NT	NT	**1**		**1**
112	Sanderling	*Calidris alba*	M	LC	EN	**1**		**1**
113	Little Stint	*Calidris minuta*	M	LC	DD			
114	Pectoral Sandpiper	*Calidris melanotos*	M	LC	NE			
115	Asian Dowitcher	*Limnodromus semipalmatus*	M	NT	VU	**1**		**1**
116	Pin-tailed Snipe	*Gallinago stenura*	M	LC	VU	**1**	**1**	**1**
117	Swinhoe's Snipe	*Gallinago megala*	M	LC	VU		**1**	**1**
118	Common Snipe	*Gallinago gallinago*	M	LC	VU	**1**	**1**	**1**
119	Terek Sandpiper	*Xenus cinereus*	M	LC	EN	**1**		**1**
120	Red-necked Phalarope	*Phalaropus lobatus*	M	LC	DD			
121	Common Sandpiper	*Actitis hypoleucos*	M	LC	VU	**1**	**1**	**1**
122	Green Sandpiper	*Tringa ochropus*	M	LC	LC	**1**	**1**	**1**
123	Grey-tailed Tattler	*Tringa brevipes*	M	NT	VU	**1**	**1**	**1**
124	Common Redshank	*Tringa totanus*	M	LC	VU	**1**	**1**	**1**
125	Marsh Sandpiper	*Tringa stagnatilis*	M	LC	EN	**1**	**1**	**1**
126	Wood Sandpiper	*Tringa glareola*	M	LC	EN	**1**	**1**	**1**
127	Spotted Redshank	*Tringa erythropus*	M	LC	NE	**1**		**1**
128	Common Greenshank	*Tringa nebularia*	M	LC	VU	**1**	**1**	**1**
129	Nordmann's Greenshank	*Tringa guttifer*	M	EN	EN	**1**		**1**

Appendix 1 *(Cont'd)*

130	Oriental Pratincole	*Glareola maldivarum*	M	LC	EN	**1**	**1**	**1**
131	Small Pratincole	*Glareola lactea*	M	LC	NE			
132	Brown-headed Gull	*Chroicocephalus brunnicephalus*	M	LC	NE	**1**		**1**
133	Black-headed Gull	*Chroicocephalus ridibundus*	M	LC	NT	**1**	**1**	**1**
134	Gull-billed Tern	*Gelochelidon nilotica*	M	LC	DD	**1**	**1**	**1**
135	Caspian Tern	*Hydroprogne caspia*	M	LC	NE			**1**
136	Greater Crested Tern	*Thalasseus bergii*	M	LC	EN	**1**		**1**
137	Lesser Crested Tern	*Thalasseus bengalensis*	M	LC	EN	**1**		**1**
138	Little Tern	*Sternula albifrons*	R/M	LC	EN	**1**	**1**	**1**
139	Aleutian Tern	*Onychoprion aleuticus*	M	VU	VU			**1**
140	Bridled Tern	*Onychoprion anaethetus*	M	LC	EN			
141	Black-naped Tern	*Sterna sumatrana*	R	LC	EN	**1**		**1**
142	Common Tern	*Sterna hirundo*	M	LC	LC	**1**	**1**	**1**
143	Whiskered Tern	*Chlidonias hybrida*	M	LC	LC	**1**	**1**	**1**
144	White-winged Tern	*Chlidonias leucopterus*	M	LC	EN	**1**	**1**	**1**
145	Parasitic Jaeger	*Stercorarius parasiticus*	M	LC	LC	**1**		**1**
146	Long-tailed Jaeger	*Stercorarius longicaudus*	M	LC	LC			
147	Swinhoe's Storm Petrel	*Hydrobates monorhis*	M	NT	NT			
148	Wedge-tailed Shearwater	*Ardenna pacifica*	M	LC	NE			

Appendix 1 *(Cont'd)*

149	Short-tailed Shearwater	*Puffinus tenuirostris*	M	LC	NE			
150	Milky Stork	*Mycteria cinerea*	R	EN	NA	1	1	1
151	Painted Stork	*Mycteria leucocephala*	R	NT	NA	1	1	1
152	Asian Openbill	*Anastomus oscitans*	NBV	LC	LC	1	1	1
153	Lesser Adjutant	*Leptoptilos javanicus*	NBV	VU	VU	1	1	1
154	Christmas Frigatebird	*Fregata andrewsi*	NBV	VU	NE	1		1
155	Lesser Frigatebird	*Fregara ariel*	NBV	LC	LC			
156	Red-footed Booby	*Sula sula*	NBV	LC	LC			
157	Brown Booby	*Sula leucogaster*	NBV	LC	LC	1		1
158	Oriental Darter	*Anhinga melanogaster*	NBV	NT	NT	1	1	1
159	**Black-headed Ibis**	*Threskiornis melanocephalus*	NBV	NT	NE	1		1
160	Glossy Ibis	*Plegadis falcinellus*	M	LC	NE	1		1
161	Yellow Bittern	*Ixobrychus sinensis*	R/M	LC	VU	1	1	1
162	Von Schrenck's Bittern	*Ixobrychus eurhythmus*	M	LC	NT	1	1	1
163	Cinnamon Bittern	*Ixobrychus cinnamomeus*	R/M	LC	VU	1	1	1
164	Black Bittern	*Dupetor flavicollis*	M	LC	LC	1	1	1
165	Malayan Night Heron	*Gorsachius melanolophus*	M	LC	NT	1	1	1
166	Black-crowned Night Heron	*Nycticorax nycticorax*	R	LC	EN	1	1	1
167	Striated Heron	*Butorides striata*	R/M	LC	NT	1	1	1

Appendix 1 *(Cont'd)*

168	Indian Pond Heron	*Ardeola grayii*	M	LC	NE			
169	Chinese Pond Heron	*Ardeola bacchus*	M	LC	LC	**1**	**1**	**1**
170	Javan Pond Heron	*Ardeola speciosa*	M	LC	LC	**1**		**1**
171	Eastern Cattle Egret	*Bubulcus coromandus*	R/M	LC	VU	**1**	**1**	**1**
172	Grey Heron	*Ardea cinerea*	R	LC	LC	**1**	**1**	**1**
173	Great-billed Heron	*Ardea sumatrana*	R	LC	CR	**1**	**1**	**1**
174	Purple Heron	*Ardea purpurea*	R	LC	EN	**1**	**1**	**1**
175	Great Egret	*Ardea alba*	M	LC	VU	**1**	**1**	**1**
176	Intermediate Egret	*Egretta intermedia*	M	LC	LC	**1**	**1**	**1**
177	Little Egret	*Egretta garzetta*	M	LC	LC	**1**	**1**	**1**
178	Pacific Reef Heron	*Egretta sacra*	R	LC	EN	**1**		**1**
179	Chinese Egret	*Egretta eulophotes*	M	VU	EN	**1**	**1**	**1**
180	Western Osprey	*Pandion haliaetus*	NBV	LC	LC	**1**	**1**	**1**
181	Black-winged Kite	*Elanus caeruleus*	R	LC	VU	**1**	**1**	**1**
182	Crested Honey Buzzard	*Pernis ptilorhynchus*	M	LC	LC	**1**	**1**	**1**
183	Jerdon's Baza	*Aviceda jerdoni*	M	LC	LC			
184	Black Baza	*Aviceda leuphotes*	M	LC	LC	**1**	**1**	**1**
185	Himalayan Vulture	*Gyps himalayensis*	M	NT	NT	**1**		**1**
186	Cinereous Vulture	*Aegypius monachus*	M	NT	NE			

Appendix 1 *(Cont'd)*

187	Crested Serpent Eagle	*Spilornis cheela*	R	LC	CR	**1**	**1**	**1**
188	Short-toed Snake Eagle	*Circaetus gallicus*	M	LC	LC	**1**	**1**	**1**
189	Bat Hawk	*Macheiramphus alcinus*	NBV	LC	LC			
190	Changeable Hawk-Eagle	*Nisaetus cirrhatus*	R	LC	VU	**1**	**1**	**1**
191	Rufous-bellied Eagle	*Lophotriorchis kienerii*	M	NT	LC	**1**	**1**	**1**
192	Greater Spotted Eagle	*Clanga clanga*	M	VU	VU	**1**	**1**	**1**
193	Booted Eagle	*Hieraaetus pennatus*	M	LC	LC		**1**	**1**
194	Steppe Eagle	*Aquila nipalensis*	M	EN	NE			
195	Eastern Imperial Eagle	*Aqula heliaca*	M	VU	NE		**1**	**1**
196	Crested Goshawk	*Accipiter trivirgatus*	R	LC	NT	**1**	**1**	**1**
197	Shikra	*Accipiter badius*	M	LC	NE			
198	Chinese Sparrowhawk	*Accipiter soloensis*	M	LC	LC	**1**	**1**	**1**
199	Japanese Sparrowhawk	*Accipiter gularis*	M	LC	LC	**1**	**1**	**1**
200	Besra	*Accipiter virgatus*	M	LC	LC			
201	Eurasian Sparrowhawk	*Accipiter nisus*	M	LC	NE			
202	Eastern Marsh Harrier	*Circus spilonotus*	M	LC	EN	**1**	**1**	**1**
203	Pied Harrier	*Circus melanoleucos*	M	LC	LC		**1**	**1**
204	Black Kite	*Milvus migrans*	M	LC	EN	**1**	**1**	**1**
205	Brahminy Kite	*Haliastur indus*	R	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

206	White-bellied Sea Eagle	*Haliaeetus leucogaster*	R	LC	LC	**1**	**1**	**1**
207	Grey-headed Fish Eagle	*Haliaeetus ichthyaetus*	R	NT	VU	**1**	**1**	**1**
208	Grey-faced Buzzard	*Butastur indicus*	M	LC	NT	**1**	**1**	**1**
209	Common Buzzard	*Buteo buteo*	M	LC	LC	**1**	**1**	**1**
210	Eastern Barn Owl	*Tyto javanica*	R	LC	LC	**1**		**1**
211	Northern Boobook	*Ninox japonica*	M	LC	DD	**1**		**1**
212	Brown Hawk-Owl	*Ninox scutulata*	R	LC	LC			
213	Oriental Scops Owl	*Otus sunia*	M	LC	NT	**1**		**1**
214	Sunda Scops Owl	*Otus lempiji*	R	LC	LC	**1**	**1**	**1**
215	Long-eared Owl	*Asio otus*	M	LC	NE			
216	Short-eared Owl	*Asio flammeus*	M	LC	LC			
217	Barred Eagle-Owl	*Bubo sumatranus*	NBV	NT	CR			
218	Buffy Fish Owl	*Ketupa ketupu*	R	LC	VU	**1**	**1**	**1**
219	Spotted Wood Owl	*Strix seloputo*	R	LC	VU	**1**	**1**	**1**
220	Brown Wood Owl	*Strix leptogrammica*	R	LC	CR			
221	Oriental Pied Hornbill	*Anthracoceros albirostris*	R	LC	NT	**1**	**1**	**1**
222	Black Hornbill	*Anthracoceros malayanus*	NBV	VU	NT			
223	Oriental Dollarbird	*Eurystomus orientalis*	R/M	LC	LC	**1**	**1**	**1**
224	Stork-billed Kingfisher	*Pelargopsis capensis*	R	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

225	Ruddy Kingfisher	*Halcyon coromanda*	R/M	LC	CR	**1**	**1**	**1**
226	White-throated Kingfisher	*Halcyon smyrnensis*	R	LC	LC	**1**	**1**	**1**
227	Black-capped Kingfisher	*Halcyon pileata*	M	VU	VU	**1**	**1**	**1**
228	Collared Kingfisher	*Todiramphus chloris*	R	LC	LC	**1**	**1**	**1**
229	Blue-eared Kingfisher	*Alcedo meninting*	R	LC	EN	**1**	**1**	**1**
230	Common Kingfisher	*Alcedo atthis*	M	LC	VU	**1**	**1**	**1**
231	Oriental Dwarf Kingfisher	*Ceyx erithaca*	M	LC	NT	**1**		**1**
232	Pied Kingfisher	*Ceryle rudis*	M	LC	NE			
233	Blue-tailed Bee-eater	*Merops philippinus*	M	LC	LC	**1**	**1**	**1**
234	Blue-throated Bee-eater	*Merops viridis*	MB	LC	LC	**1**	**1**	**1**
235	Lineated Barbet	*Psilopogon lineatus*	R	LC	NA	**1**	**1**	**1**
236	Red-crowned Barbet	*Psilopogon rafflesii*	R	NT	VU			
237	Coppersmith Barbet	*Psilopogon haemacephalus*	R	LC	LC	**1**	**1**	**1**
238	Sunda Pygmy Woodpecker	*Dendrocopus moluccensis*	R	LC	LC	**1**	**1**	**1**
239	White-bellied Woodpecker	*Dryocopus javensis*	R	LC	CR			
240	Banded Woodpecker	*Chrysophlegma miniaceum*	R	LC	LC	**1**	**1**	**1**
241	Crimson-winged Woodpecker	*Picus puniceus*	NBV	LC	LC			
242	Laced Woodpecker	*Picus vittatus*	R	LC	LC	**1**	**1**	**1**
243	Common Flameback	*Dinopium javanense*	R	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

244	Rufous Woodpecker	*Micropternus brachyurus*	R	LC	LC	**1**	**1**	**1**
245	Buff-rumped Woodpecker	*Meiglyptes tristis*	NBV	LC	LC			
246	Great Slaty Woodpecker	*Mulleripicus pulverulentus*	NBV	VU	VU			
247	Black-thighed Falconet	*Microhierax fringillarius*	R	LC	LC			
248	Lesser Kestrel	*Falco naumanni*	M	LC	NE			
249	Common Kestrel	*Falco tinnunculus*	M	LC	LC	**1**	**1**	**1**
250	Amur Falcon	*Falco amurensis*	M	LC	NE			
251	Eurasian Hobby	*Falco subbuteo*	M	LC	NE			
252	Peregrine Falcon	*Falco peregrinus*	M	LC	LC	**1**	**1**	**1**
253	Tanimbar Corella	*Cacatua goffiniana*	R	NT	NA	**1**	**1**	**1**
254	Yellow-crested Cockatoo	*Cacatua sulphurea*	R	CR	NA			
255	Blue-rumped Parrot	*Psittinus cyanurus*	R	NT	EN			
256	Red-breasted Parakeet	*Psittacula alexandri*	R	NT	NA	**1**	**1**	**1**
257	Long-tailed Parakeet	*Psittacula longicauda*	R	VU	NT	**1**	**1**	**1**
258	Rose-ringed Parakeet	*Psittacula krameri*	R	LC	NA	**1**	**1**	**1**
259	Coconut Lorikeet	*Trichoglossus haematodus*	R	LC	NA		**1**	**1**
260	Blue-crowned Hanging Parrot	*Loriculus galgulus*	R	LC	LC	**1**	**1**	**1**
261	Black-and-red Broadbill	*Cymbirhynchus macrorhynchos*	NBV	LC	CR	**1**		**1**
262	Green Broadbill	*Calyptomena viridis*	NBV	NT	NT			

Appendix 1 *(Cont'd)*

263	Blue-winged Pitta	*Pitta moluccensis*	M	LC	LC	**1**	**1**	**1**
264	Mangrove Pitta	*Pitta megarhyncha*	R	NT	CR	**1**		**1**
265	Hooded Pitta	*Pitta sordida*	M	LC	LC			
266	Fairy Pitta	*Pitta nympha*	**M**	VU	DD			
267	Golden-bellied Gerygone	*Gerygone sulphurea*	R	LC	NT	**1**	**1**	**1**
268	Black-winged Flycatcher-shrike	*Hemipus hirundinaceus*	NBV	LC	DD			
269	Large Woodshrike	*Tephrodornis virgatus*	NBV	LC	DD			
270	Common Iora	*Aegithina tiphia*	R	LC	LC	**1**	**1**	**1**
271	Scarlet Minivet	*Pericrocotus speciosus*	R	LC	CR			
272	Ashy Minivet	*Pericrocotus divaricatus*	M	LC	LC	**1**	**1**	**1**
273	Pied Triller	*Lalage nigra*	R	LC	LC	**1**	**1**	**1**
274	Lesser Cuckooshrike	*Coracina fimbriata*	R	LC	CR			
275	Mangrove Whistler	*Pachycephala cinerea*	R	LC	EN	**1**		**1**
276	Tiger Shrike	*Lanius tigrinus*	M	LC	NT	**1**	**1**	**1**
277	Brown Shrike	*Lanius cristatus*	M	LC	VU	**1**	**1**	**1**
278	Long-tailed Shrike	*Lanius schach*	R	LC	LC	**1**	**1**	**1**
279	White-bellied Erpornis	*Erpornis zantholeuca*	NBV	LC	LC			
280	Black-naped Oriole	*Oriolus chinensis*	R	LC	LC	**1**	**1**	**1**
281	Crow-billed Drongo	*Dicrurus annectans*	M	LC	NT	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

282	Greater Racket-tailed Drongo	*Dicrurus paradiseus*	R	LC	LC	**1**	**1**	**1**
283	Hair-crested Drongo	*Dicrurus hottentottus*	M	LC	NE			
284	Ashy Drongo	*Dicrurus leucophaeus*	M	LC	LC	**1**	**1**	**1**
285	Black Drongo	*Dicrurus macrocercus*	M	LC	VU	**1**	**1**	**1**
286	Malaysian Pied Fantail	*Rhipidura javanica*	R	LC	LC	**1**	**1**	**1**
287	Black-naped Monarch	*Hypothymis azurea*	R	LC	CR			
288	Indian Paradise Flycatcher	*Terpsiphone paradisi*	M	LC	NE	**1**		**1**
289	Blyth's Paradise Flycatcher	*Terpsiphone affinis*	M	LC	LC	**1**	**1**	**1**
290	Amur Paradise Flycatcher	*Terpsiphone incei*	M	LC	LC	**1**	**1**	**1**
291	Japanese Paradise Flycatcher	*Terpsiphone atrocaudata*	M	NT	NT	**1**	**1**	**1**
292	Malayan Black Magpie	*Platysmurus leucopterus*	NBV	LC	NE			
293	House Crow	*Corvus splendens*	R	LC	NA	**1**	**1**	**1**
294	Large-billed Crow	*Corvus macrorhynchos*	R	LC	VU	**1**	**1**	**1**
295	Japanese Tit	*Parus minor*	M	LC	NE			
296	Eurasian Skylark	*Alauda arvensis*	M	LC	NE			
297	Buff-vented Bulbul	*Iole olivacea*	R	NT	CR			
298	Cinereous Bulbul	*Hemixos cinereus*	NBV	LC	LC	**1**		**1**
299	Streaked Bulbul	*Ixos malaccensis*	NBV	NT	NT	**1**		**1**
300	Black-and-white Bulbul	*Pycnonotus melanoleucos*	NBV	NT	NT			

Appendix 1 *(Cont'd)*

301	Black-headed Bulbul	*Pycnonotus atriceps*	R	LC	CR	**1**		**1**
302	Black-crested Bulbul	*Pycnonotus flaviventris*	R	LC	NA			
303	Cream-vented Bulbul	*Pycnonotus simplex*	R	LC	VU			
304	Olive-winged Bulbul	*Pycnonotus plumosus*	R	LC	LC	**1**	**1**	**1**
305	Asian Red-eyed Bulbul	*Pycnonotus brunneus*	R	LC	VU	**1**		**1**
306	Straw-headed Bulbul	*Pycnonotus zeylanicus*	R	CR	EN	**1**	**1**	**1**
307	Stripe-throated Bulbul	*Pycnonotus finlaysoni*		LC	NE			
308	Red-whiskered Bulbul	*Pycnonotus jocosus*	R	LC	NA	**1**	**1**	**1**
309	Yellow-vented Bulbul	*Pycnonotus goiavier*	R	LC	LC	**1**	**1**	**1**
310	Sooty-headed Bulbul	*Pycnonotus aurigaster*	R	LC	NA	**1**	**1**	**1**
311	Sand Martin	*Riparia riparia*	M	LC	LC	**1**	**1**	**1**
312	Pacific Swallow	*Hirundo tahitica*	R	LC	LC	**1**	**1**	**1**
313	Barn Swallow	*Hirundo rustica*	M	LC	NT	**1**	**1**	**1**
314	Siberian House Martin	*Delichon lagopodum*	M	LC	NE			
315	Asian House Martin	*Delichon dasypus*	M	LC	LC	**1**	**1**	**1**
316	Red-rumped Swallow	*Cecropis daurica*	M	LC	LC	**1**	**1**	**1**
317	Yellow-browed Warbler	*Phylloscopus inornatus*	M	LC	LC	**1**	**1**	**1**
318	Dusky Warbler	*Phylloscopus fuscatus*	M	LC	NE			
319	Eastern Crowned Warbler	*Phylloscopus coronatus*	M	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

320	Sakhalin Leaf Warbler	*Phylloscopus borealoides*	M	LC	NT	**1**		**1**
321	Pale-legged Leaf Warbler	*Phylloscopus tenellipes*	M	LC	NE			
322	Arctic Warbler	*Phylloscopus borealis*	M	LC	LC	**1**	**1**	**1**
323	Oriental Reed Warbler	*Acrocephalus orientalis*	M	LC	VU	**1**	**1**	**1**
324	Black-browed Reed Warbler	*Acrocephalus bistrigiceps*	M	LC	NT	**1**	**1**	**1**
325	Booted Warbler	*Iduna caligata*	M	LC	NE		**1**	**1**
326	Pallas's Grasshopper Warbler	*Locustella certhiola*	M	LC	LC	**1**	**1**	**1**
327	Lanceolated Warbler	*Locustella lanceolata*	M	LC	NT	**1**	**1**	**1**
328	Zitting Cisticola	*Cisticola juncidis*	R	LC	VU	**1**	**1**	**1**
329	Yellow-bellied Prinia	*Prinia flaviventris*	R	LC	NT	**1**	**1**	**1**
330	Common Tailorbird	*Orthotomus sutorius*	R	LC	LC	**1**	**1**	**1**
331	Dark-necked Tailorbird	*Orthotomus atrogularis*	R	LC	LC	**1**	**1**	**1**
332	Rufous-tailed Tailorbird	*Orthotomus sericeus*	R	LC	NT	**1**	**1**	**1**
333	Ashy Tailorbird	*Orthotomus ruficeps*	R	LC	LC	**1**	**1**	**1**
334	Swinhoe's White-eye	*Zosterops simplex*	R	LC	VU	**1**	**1**	**1**
335	Pin-striped Tit-Babbler	*Macronous gularis*	R	LC	LC	**1**	**1**	**1**
336	Chestnut-winged Babbler	*Stachyris erythroptera*	R	LC	CR			
337	Moustached Babbler	*Malacopteron magnirostre*	R	LC	CR			
338	Short-tailed Babbler	*Malacocincla malaccensis*	R	NT	VU			

Appendix 1 *(Cont'd)*

339	White-chested Babbler	*Trichastoma rostratum*	R	NT	CR	**1**	**1**	**1**
340	Abbott's Babbler	*Malacocincla abbotti*	R	LC	LC	**1**	**1**	**1**
341	Chinese Hwamei	*Garrulax canorus*	R	LC	NA			
342	White-crested Laughingthrush	*Garrulax leucolophus*	R	LC	NA	**1**	**1**	**1**
343	Asian Fairy-bluebird	*Irena puella*	R	LC	NT			
344	Velvet-fronted Nuthatch	*Sitta frontalis*	NBV	LC	LC			
345	Asian Glossy Starling	*Aplonis panayensis*	R	LC	LC	**1**	**1**	**1**
346	Common Hill Myna	*Gracula religiosa*	R	LC	NT	**1**	**1**	**1**
347	Javan Myna	*Acridotheres javanicus*	R	VU	NA	**1**	**1**	**1**
348	Common Myna	*Acridotheres tristis*	R	LC	LC	**1**	**1**	**1**
349	Red-billed Starling	*Spodiopsar sericeus*	M	LC	NE			
350	White-cheeked Starling	*Spodiopsar cineraceus*	M	LC	NE			
351	Daurian Starling	*Agropsar sturninus*	M	LC	LC	**1**	**1**	**1**
352	Chestnut-cheeked Starling	*Agropsar philippensis*	M	LC	DD			
353	White-shouldered Starling	*Sturnia sinensis*	M	LC	LC		**1**	**1**
354	Brahminy Starling	*Sturnia pagodarum*	M	LC	NE			
355	Rosy Starling	*Pastor roseus*	M	LC	NE			
356	Common Starling	*Sturnus vulgaris*	M	LC	NE			
357	Siberian Thrush	*Geokichla sibirica*	M	LC	NT			

Appendix 1 *(Cont'd)*

358	Orange-headed Thrush	*Geokichla citrina*	M	LC	NT			
359	Chinese Blackbird	*Turdus mandarinus*	M	LC	NE			
360	Eyebrowed Thrush	*Turdus obscurus*	M	LC	NT		**1**	**1**
361	Oriental Magpie-Robin	*Copsychus saularis*	R	LC	VU	**1**	**1**	**1**
362	White-rumped Shama	*Copsychus malabaricus*	R	LC	EN	**1**	**1**	**1**
363	Spotted Flycatcher	*Muscicapa striata*	M	LC	NE			
364	Grey-streaked Flycatcher	*Muscicapa griseisticta*	M	LC	NE			
365	Dark-sided Flycatcher	*Muscicapa sibirica*	M	LC	NT	**1**	**1**	**1**
366	Asian Brown Flycatcher	*Muscicapa dauurica*	M	LC	LC	**1**	**1**	**1**
367	Brown-streaked Flycatcher	*Muscicapa williamsoni*	M	LC	LC		**1**	**1**
368	Brown-breasted Flycatcher	*Muscicapa muttui*		LC	NE			
369	Ferruginous Flycatcher	*Muscicapa ferruginea*	M	LC	NT	**1**		**1**
370	Chinese Blue Flycatcher	*Cyornis glaucicomans*	M	LC	NT	**1**		**1**
371	Mangrove Blue Flycatcher	*Cyornis rufigastra*	R	LC	CR	**1**		**1**
372	Brown-chested Jungle Flycatcher	*Cyornis brunneatus*	M	VU	VU	**1**		**1**
373	Blue-and-white Flycatcher	*Cyanoptila cyanomelana*	M	LC	NT			
374	Zappey's Flycatcher	*Cyanoptila cumatilis*	M	NT	NT			
375	Verditer Flycatcher	*Eumyias thalassinus*	NBV	LC	NE			
376	Siberian Blue Robin	*Larvivora cyane*	M	LC	NT	**1**		**1**

Appendix 1 *(Cont'd)*

377	Yellow-rumped Flycatcher	*Ficedula zanthopygia*	M	LC	LC	**1**	**1**	**1**
378	Green-backed Flycatcher	*Ficedula elisae*	M	LC	NT	**1**		**1**
379	Narcissus Flycatcher	*Ficedula narcissina*	M	LC	DD			
380	Mugimaki Flycatcher	*Ficedula mugimaki*	M	LC	LC	**1**		**1**
381	Taiga Flycatcher	*Ficedula albicilla*	M	LC	NE			
382	Black Redstart	*Phoenicurus ochruros*	M	LC	NE			
383	Daurian Redstart	*Phoenicurus auroreus*	M	LC	NE			
384	Blue Rock Thrush	*Monticola soltarius*	M	LC	LC			
385	White-throated Rock Thrush	*Monticola gularis*	M	LC	NT			
386	Amur Stonechat	*Saxicola stejnegeri*	M	NE	NE	**1**	**1**	**1**
387	Greater Green Leafbird	*Chloropsis sonnerati*	R	EN	CR			
388	Lesser Green Leafbird	*Chloropsis cyanopogon*	R	NT	CR			
389	Blue-winged Leafbird	*Chloropsis cochinchinensis*	R	EN	NT			
390	Scarlet-breasted Flowerpecker	*Prionochilus thoracicus*	NBV	NT	NT			
391	Thick-billed Flowerpecker	*Dicaeum agile*	NBV	LC	DD			
392	Yellow-vented Flowerpecker	*Dicaeum chrysorrheum*	R	LC	CR			
393	Orange-bellied Flowerpecker	*Dicaeum trigonostigma*	R	LC	NT	**1**	**1**	**1**
394	Scarlet-backed Flowerpecker	*Dicaeum cruentatum*	R	LC	LC	**1**	**1**	**1**
395	Ruby-cheeked Sunbird	*Chalcoparia singalensis*	NBV	LC	DD	**1**		**1**

Appendix 1 *(Cont'd)*

396	Brown-throated Sunbird	*Anthreptes malacensis*	R	LC	LC	**1**	**1**	**1**
397	Van Hasselt's Sunbird	*Leptocoma brasiliana*	R	LC	LC	**1**		**1**
398	Copper-throated Sunbird	*Leptocoma calcostetha*	R	LC	VU	**1**	**1**	**1**
399	Olive-backed Sunbird	*Cinnyris jugularis*	R	LC	LC	**1**	**1**	**1**
400	Crimson Sunbird	*Aethopyga siparaja*	R	LC	LC	**1**	**1**	**1**
401	Little Spiderhunter	*Arachnothera longirostra*	R	LC	NT	**1**		**1**
402	Thick-billed Spiderhunter	*Arachnothera crassirostris*	R	LC	CR			
403	Yellow-eared Spiderhunter	*Arachnothera chrysogenys*	R	LC	CR			
404	Eurasian Tree Sparrow	*Passer montanus*	R	LC	LC	**1**	**1**	**1**
405	House Sparrow	*Passer domesticus*	R	LC	NA			
406	Streaked Weaver	*Ploceus manyar*	R	LC	NA	**1**		**1**
407	Baya Weaver	*Ploceus philippinus*	R	LC	VU	**1**	**1**	**1**
408	Scaly-breasted Munia	*Lonchura punctulata*	R	LC	LC	**1**	**1**	**1**
409	White-rumped Munia	*Lonchura striata*	R	LC	CR	**1**	**1**	**1**
410	Javan Munia	*Lonchura leucogastroides*	R	LC	NA	**1**	**1**	**1**
411	Chestnut Munia	*Lonchura atricapilla*	R	LC	VU	**1**	**1**	**1**
412	White-headed Munia	*Lonchura maja*	R	LC	LC	**1**	**1**	**1**
413	Red Avadavat	*Amandava amandava*	R	LC	NE	**1**	**1**	**1**
414	Forest Wagtail	*Dendronanthus indicus*	M	LC	LC	**1**	**1**	**1**

Appendix 1 *(Cont'd)*

415	Eastern Yellow Wagtail	*Motacilla tschutschensis*	M	LC	VU	**1**	**1**	**1**
416	Citrine Wagtail	*Motacilla citreola*	M	LC	NE			**1**
417	Grey Wagtail	*Motacilla cinerea*	M	LC	LC	**1**	**1**	**1**
418	White Wagtail	*Motacilla alba*	M	LC	LC	**1**	**1**	**1**
419	Paddyfield Pipit	*Anthus rufulus*	R	LC	LC	**1**	**1**	**1**
420	Tree Pipit	*Anthus trivialis*	M	LC	NE			
421	Olive-backed Pipit	*Anthus hodgsoni*	M	LC	NE			
422	Red-throated Pipit	*Anthus cervinus*	M	LC	LC		**1**	**1**
	Total					**281**	**235**	**298**

Notes:

This 2023 Singapore Species list was shared by the Nature Society (Singapore) Bird Group.

Key:

R – resident, NBV – Non-breeding visitor, M – Migrant.

LC – Least Concern, NT – Near Threatened, VU – Vulnerable, EN – Endangered, CR – Critically Endangered, DD – Data Deficient, NA – Not Applicable, NE – Not Evaluated.

CHAPTER 11

Restoration of a Diversity of Ecosystems on Coney Island Park

Tan Yit Chuan, Neo Meng Yang, Amanda Ng, Daniel Ng Choong Hern
& Kalthom binte Abd Latiff

Introduction

Coney Island Park, which was opened to the public in October 2015, is an 87-hectare park (Fig. 1) that supports a wide variety of habitats, consisting predominantly of Casuarina woodlands, coastal forests, grasslands, mangroves and intertidal zones (Fig. 2). To showcase Coney Island Park as an example of sustainable development in conservation and ecological restoration, the National Parks Board (NParks) commenced several habitat enhancements and restoration projects on the island in 2015. The effort is ongoing with further enhancement works being carried out progressively. The main objectives were to improve the existing Casuarina woodlands so that Coney Island Park would have more diverse native coastal forest habitats and to increase the canopy cover and understorey species composition. The native species planted on the island were carefully selected (1) to safeguard the ecological value of native coastal plants, (2) to restore the island's ecological function by providing more conducive habitats for the diverse flora and fauna to thrive, and (3) to allow natural succession to occur with minimum intervention.

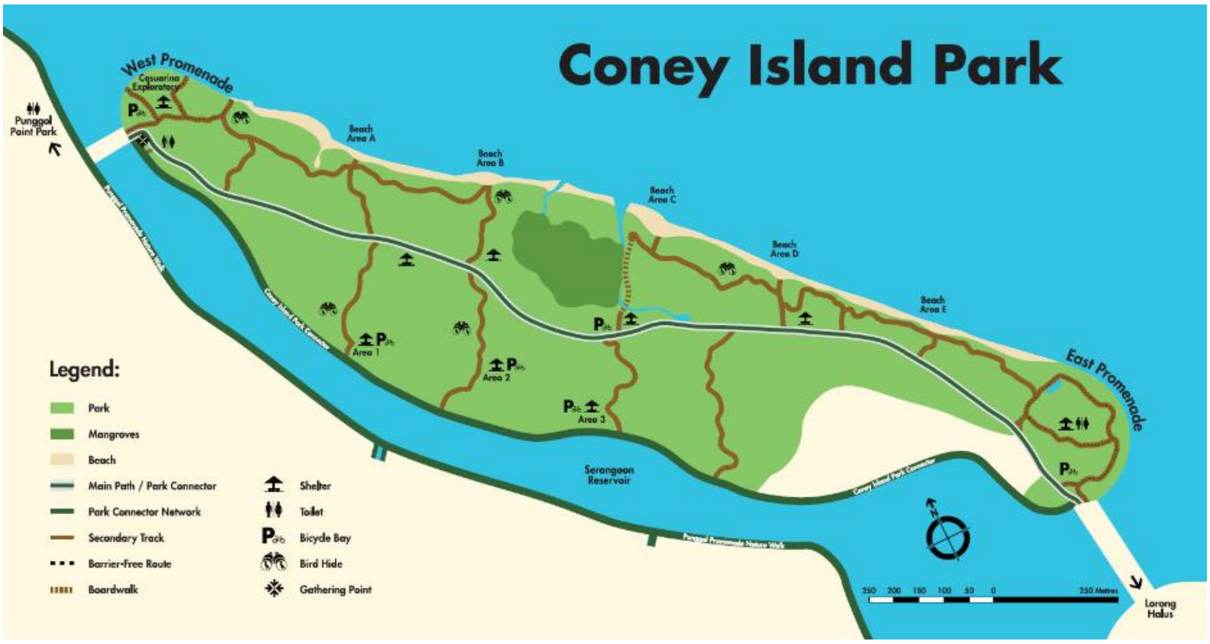


Fig. 1. Map of Coney Island Park.

Fig 2. Variety of habitats on Coney Island Park.

Floral Biodiversity

To enhance the floral biodiversity of Coney Island Park, a landscape planting palette was specially curated for various localities on the island. For example, each of the five beach areas in the park was meant to be home to plants of a particular habitat or theme (Fig. 3). The existing vegetation and relationship with sea level were carefully analysed to determine the species of native coastal plants and trees that would be reintroduced into the areas.

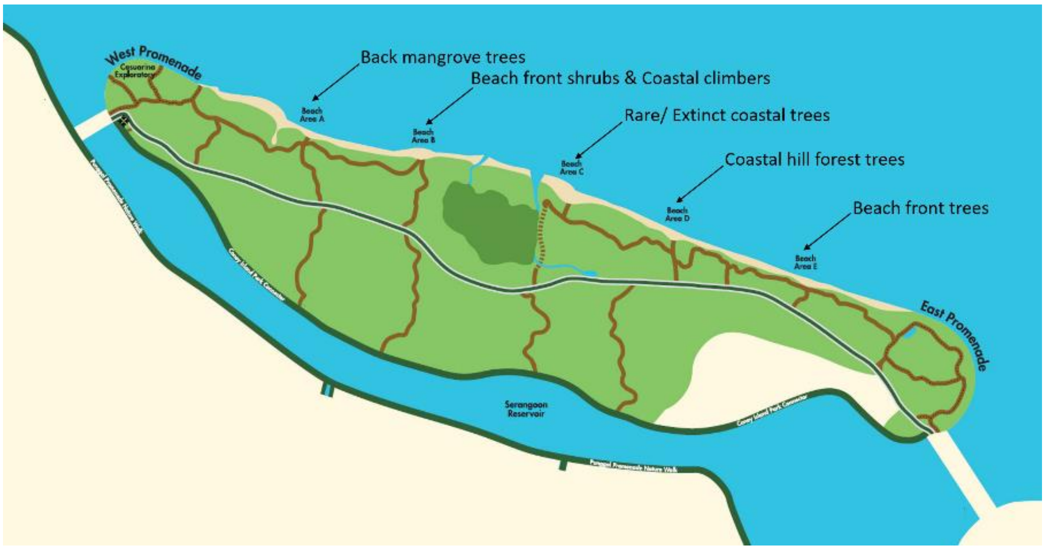


Fig. 3. Location of the five beaches and their themes.

Thematic beach plantings – rare and extinct trees at Beach Area C

The curated planting palette for Beach Area C included trees with rare or extinct conservation status in the wild. Examples of some of the rare plants that can be found near Beach Area C are shown below.

i. Cycads or Paku Rajah (*Cycas edentata*)

The cycads near Beach C were rescued from a site in Katong that was slated for development and were replanted here in their native beach habitat. Locally rare in the wild, cycads have a long fossil history and typically grow very slowly. Some specimens are believed to have lived for as long as 1,000 years. Cycads do not produce flowers, but instead are cone-bearing.

Fig. 4. Cycads on Coney Island Park.

ii. Sea-hearse or Buah Keras Laut (*Hernandia nymphaeifolia*)

The Sea-hearse is an evergreen seashore tree that grows up to 22 m tall. It has long-stalked leaves with somewhat fleshy, leathery blades with yellowish veins and midribs. Growing most commonly along sandy and rocky coasts, the tree bears fragrant, yellowish white flowers. The species is presumed to be extinct in Singapore, and Coney Island Park is the first location where it is being reintroduced into the natural environment.

Fig. 5. Sea-hearse (*Hernandia nymphaeifolia*).

iii. Pokok Rukam Gajah (*Scolopia macrophylla*)

Native to Singapore, the Pokok Rukam Gajah is a small thorny tree with tooth-edged leaves. The flowers are greenish-white and the fruit matures from orange to black. This is the only species of *Scolopia* that occurs in Singapore. Once presumed to be locally extinct, it was rediscovered at Coney Island Park in 2014.

Fig. 6. Pokok Rukam Gajah (*Scolopia macrophylla*).

Other rare/extinct trees planted near Beach Area C include the following:

Trees	Shrubs
Melaleuca cajuputi	*Pluchea indica*
Ormosia sumatrana	*Pemphis acidula*
Pongamia pinnata	*Sophora tomentosa*
Syzygium syzygioides	*Tarenna fragrans*
Serianthes grandiflora	

The key species that were planted in the other beach areas, namely Beach Areas A, B, D and E, are presented below:

Table 1: Key species planted in Beach Areas A, B, D, and E.

Beach Area	Habitat/ Theme	Endangered/ Extinct plant(s)	Remarks
A	Back mangrove trees	Penaga Laut (*Calophyllum inophyllum*) (Status: Critically Endangered)	As it is naturally occurring on Coney Island, *Calophyllum inophyllum* is the main species planted in this area.
		Dungun (*Heriteria littoralis*) (Status: Critically Endangered)	The Dungun tree produces durable timber that is used for making telegraph poles in the past.
B	Beachfront shrubs and coastal climbers	Pink-Eyed Pong Pong (*Cerbera manghas*) (Status: Critically Endangered)	It resembles another congeneric species, *Cerbera odollam*, and can be readily told apart by the yellow-centred flowers. *Cerbera manghas* has red- to pink-centred flowers and is much rarer locally, and is only known from populations in Pulau Semakau, Pulau Ubin, and St. John's Island.
		Twin-Apple (*Ochrosia oppositifolia*) (Status: Presumed Nationally Extinct)	The plant resembles a more neatly branching frangipani (*Plumeria* species or hybrids), and grows on rocky and sandy seashores, in beach vegetation, coastal forests, and the edge of mangrove forests. This is the first time that the *Ochrosia oppositifolia* is being planted in its natural environment after being classified as locally extinct.
D	Coastal hill forest trees	Jeliti (*Planchonella chartacea*) (Status: Critically Endangered)	First reported to occur in Singapore in 1997 from Lazarus Island, it was subsequently also found in Chek Jawa.

E	Beachfront trees	Jelawi (*Terminalia subspathulata*) (Status: Critically Endangered)	Jelawi has a rather open and tiered crown that large birds of prey use as nesting sites.
		Badam (*Terminalia copelandii*) (Status: Native to Malaysia)	The Badam looks similar to the Sea Almond (*Terminalia cattapa*). However, the leaves of this tree are much larger, and it is found in inland forests.

Coastal meadows

Coastal meadows were created at two locations on the island (Fig. 7) to enhance species variety and support and increase the island's biodiversity. They contain a selection of free-flowering plants commonly found along the sandy, coastal beaches of Singapore (Fig. 8). These species are well-adapted to the harsh conditions of coastal areas, i.e., strong light exposure, salt spray, and very windy conditions. They serve as an educational tool as well as an enhancement to the island's floral and faunal biodiversity.

Fig. 7. Map location of the planted coastal meadows.

Fig. 8. One of the coastal meadows on Coney Island Park.

Thematic plantings at Coney Island Interim Park

The area to the south of the main path was also curated with a thematic planting palette when the area was redeveloped in 2018. There were three new nodes (rest points with shelters), with each focussing on the main parts of a plant that botanists use to identify a plant: fruits, bark, and leaves (Fig. 9). Each of these nodes highlights unique types of leaves, fruits, and bark of some native plant species.

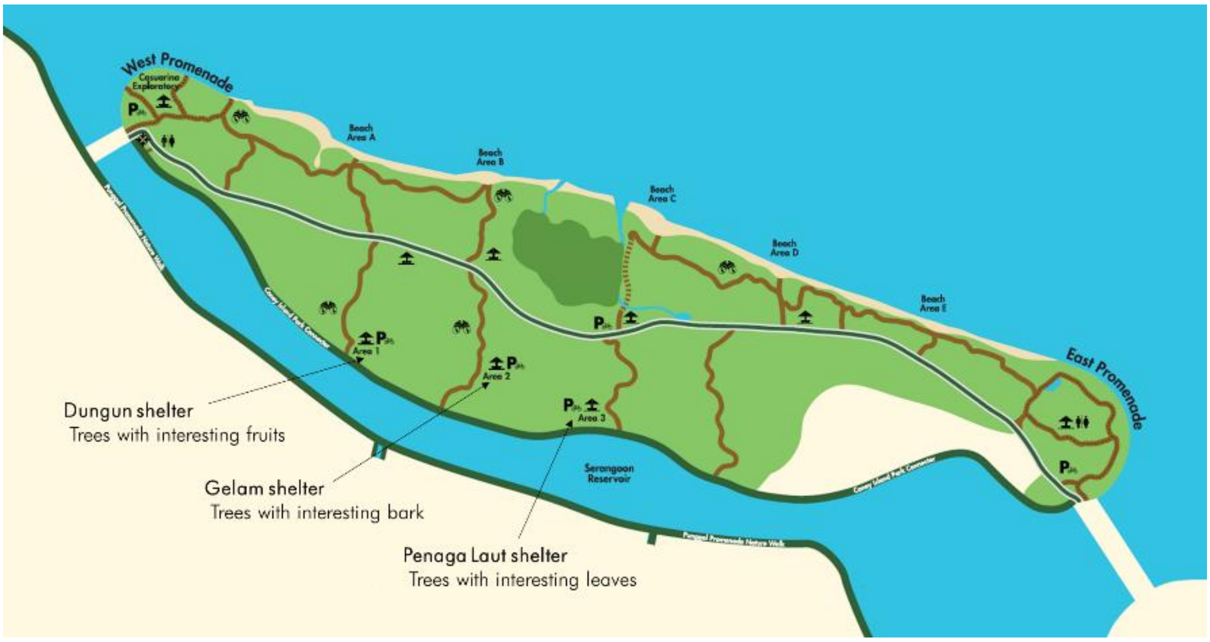


Fig. 9. Location of three new nodes with thematic planting.

i. Thematic Planting for area around Dungun Shelter: Interesting Fruits (Fig. 10)

- Mangrove Dungun (*Heritiera littoralis*) – Its egg-shaped fruit has a ridge across the length, which looks like the keel of a boat. Inside is a single seed.
- Simpoh Air (*Dillenia suffruticosa*) – Its fruit is a sphere when closed, and opens into a red star shape with about eight sections. In each section are black seeds, covered with a red flesh (aril). Many birds like the Yellow-vented Bulbul eat these seeds and help to disperse them.
- Sea Pong Pong (*Cerbera manghas*) – Its fruit looks like a mango, green when unripe, turning red as it ripens. Within it, there is a fibrous 'husk' that enables the fruit to float and be carried away by sea.
- Manggis Hutan (*Garcinia celebica*) – Its bright red fruit looks like an apple. The fruit is edible, but sour.
- Katong Laut (*Cynometra ramiflora*) – Its pod is brown and wrinkled.

<u>Trees with Interesting Fruits</u>

Mangrove Dungun

(*Heritiera littoralis*)

Simpoh Air

(*Dillenia suffruticosa*)

Sea Pong Pong

(*Cerbera manghas*)

Manggis Hutan

(*Garcinia celebica*)

Katong Laut

(*Cynometra ramiflora*)

Figs. 10. Trees with interesting fruits.

ii. Thematic planting for area around Gelam Shelter: Interesting Bark (Fig. 11)

- Sea Tristania (*Tristaniopsis obovata*) – Its bark is flaky and bright orange (sometimes grey or green).
- River Tristania (*Tristaniopsis whiteana*) – Its bark is flaky and orange/grey bark.
- Gelam Tree (*Melaleuca cajuputi*) – Its Malay name, Kayu Putih or 'white wood', refers to its white, flaky bark, which in the past was used as material for boats, life vests, and filling pillows.
- Kelat Merah (*Syzygium filiforme*) – Its bark is red, papery and flaky.
- Kayu Arang (*Cratoxylum cochinchinense*) – Its bark is smooth and colourful with brown and yellow colouring that peels off in strips.

<u>Trees with Interesting Bark</u>

Sea Tristania

(*Tristaniopsis obovata*)

River Tristania

(*Tristaniopsis whiteana*)

Gelam Tree

(*Melaleuca cajuputi*)

Kelat Merah

(*Syzygium filiforme*)

Kayu Arang

(*Cratoxylum cochinchinense*)

Figs. 11. Trees with interesting bark.

iii. Thematic Planting for area around Penaga Laut Shelter: Interesting Leaves (Fig. 12)

- Sea Gutta (*Planchonella obovata*) – Its oval leaves have two colours: green on the upper side, and reddish brown on the hairy underside.
- Star Apple (*Chrysophyllum cainito*) – Its leaves have two colours: deep green and glossy on top, and golden brown with a satin sheen on the underside.
- Penaga Laut (*Callophyllum inophyllum*) – Its leaves are oval and leathery, with many fine veins.
- Tongkat Ali (*Eurycoma longifolia*) – Each of its leaves are 1 m long, with many leaflets, which are dark green on the upper side and lighter green on the underside.

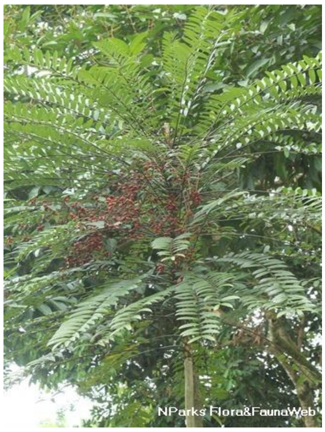
<u>Trees with Interesting Leaves</u>

Sea Gutta

(*Planchonella obovata*)

Star Apple

(*Chrysophyllum cainito*)



Tongkat Ali

(*Eurycoma longifolia*)

Penaga Laut

(*Callophyllum inophyllum*)

Figs. 12. Trees with interesting leaves.

Mangrove rehabilitation efforts along the Mangrove Boardwalk

A patch of mangrove forest on Coney Island Park can be found between Beach Area B and Beach Area C (Fig. 13), where a rivulet brings in seawater to inundate the forest. Mangrove forests, although often regarded as 'swamps', are in fact a rich habitat with a high biodiversity. The water here is brackish, a mixture of seawater and freshwater. During the development of Coney Island Park in 2015, a mangrove boardwalk was constructed alongside the rivulet to connect the island's main paths to Beach Area C.

Fig. 13. Location of the mangrove forest.

Mangrove rehabilitation efforts were carried out in 2019 to expand the existing mangrove forest and bring it nearer to the mangrove boardwalk for members of the public to appreciate the mangrove flora and fauna up close. To achieve this, the vegetated area between the rivulet and the boardwalk, that comprised mainly non-mangrove species (Fig. 14), was re-graded by removing the soil (Fig. 15) and creating earth channels for seawater to inundate the area along the boardwalk during high tide (Fig. 16). This would allow the planting of the true mangrove species along with back mangrove species (Fig. 17–19; Table 2), and hence creating a self-sustaining mangrove ecosystem with thriving mangrove flora and fauna.

Educational signs were installed so that the public can learn more about mangrove biodiversity and the ecological benefits contributed by this important ecosystem (Fig. 20).

The progression of the mangrove restoration and rehabilitation on Coney Island Park from November 2019 to June 2023 can be seen in Fig. 21.

Fig. 14. Clearing of terrestrial species along the rivulet.

Fig. 15. Regrading of soil to lower the ground level for more areas to be inundated.

Fig. 16. Trenching of channels to bring in seawater for more areas to be inundated during high tide.

Fig. 17. Preparation for the planting of mangrove saplings.

Fig. 18. Planting works in progress.

Fig. 19. Newly planted mangrove saplings.

Fig. 20. Installation of educational signs.

Figs. 21. Progress of the rehabilitated mangrove area as seen through the photos taken at different dates. (A) November 2019; (B) August 2021; (C) June 2023.

Table 2: A list of mangrove and back mangrove species that had been planted on the restoration and rehabilitated mangrove area on Coney Island Park.

Species	Qty
Avicennia rumphiana	2
Bruguiera gymnorhiza	90
Bruguiera hainesii	10
Bruguiera parviflora	15
Bruguiera sexangula	15
Sonneratia ovata	6
Rhizophora apiculata	90
Rhizophora mucronata	7
Rhizophora stylosa	5
Lumnitzera littorea	1
Lumnitzera racemosa	46

Species	Qty
Heritiera littoralis	4
Ceriops zippeliana	65
Xylocarpus granatum	2
Xylocarpus moluccensis	65
Rapanea porteriana	28
Acanthus ilicifolius	24
Acanthus ebracteatus	15
Volkameria inermis	50
Pluchea indica	30
Acrostichum speciosum	10
Scaevola taccada	20

Faunal Biodiversity

Four species of resident woodpeckers — Sunda Pygmy (*Dendrocopos moluccensis*), Laced (*Picus vittatus*), Rufous (*Micropternus brachyurus*) and Common Flameback Woodpeckers (*Dinopium javanense*) — have been recorded on Coney Island Park. The Collared Kingfisher (*Todiramphus chloris*) and White-throated Kingfisher (*Halcyon smyrnensis*) are residents on Coney Island Park. Due to woodpeckers' preference for nesting in tree holes, these species face a limited supply of natural nest sites. To increase the availability of suitable nesting sites for kingfishers and woodpeckers, nest boxes were installed on the island (Fig. 22). Bird boxes made from recycled timber were erected on tall trees in a few areas around Coney Island Park. These nest boxes also attracted kingfishers. Officers from NParks' Parks and Design divisions are currently discussing the design of new nest boxes and selection of trees that are most widely used by the birds based on monitoring observations.

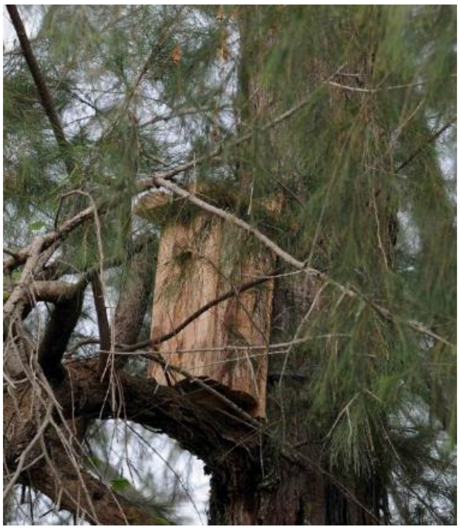


Fig. 22. Nest box on a Casuarina (*Casuarina equisetifolia*).

Enhancement plots (GCF)

The Garden City Fund (GCF), a registered charity established by NParks, has fostered valuable partnerships with various corporations and individuals, allowing NParks to achieve our vision of transforming Singapore into a City in Nature. For example, GCF's partnerships through the Plant-A-Tree (PAT) programme resulted in the planting of more than 1,000 tree saplings, comprising more than 50 native coastal plant species. The partnerships not only brought about a big leap in progress to enhance the park, but also established strong collaborative efforts in other aspects of habitat enhancement, such as the collection and propagation of seeds and plants and the conducting of learning expeditions. The collection and propagation of seeds and plants in Coney

Island Park contribute towards safeguarding the gene pool of the native plants. Furthermore, educational outreach, made possible by the partnerships, has helped widen the reach of NParks' messaging of biodiversity conservation.

Success of efforts

Habitat restoration and enhancement efforts on the island resulted in the island being home to at least 157 fauna and 86 plant species, of which some are critically endangered and presumed nationally extinct in the wild. In particular, 10 species of fauna that were listed in *The Singapore Red Data Book* (Davison *et al*., 2008) had been recorded.

Table 3. Faunal species listed in the 2nd edition of *The Singapore Red Data Book* (Source: Davison *et al*., 2008)

Birds (*Nationally Critically Endangered*) - Black-crowned Night-Heron - Spotted Wood-Owl (*Nationally Endangered*) - Red Junglefowl - Changeable Hawk-Eagle - Red-wattled Lapwing (*Nationally Vulnerable*) - Grey Heron - Rusty-breasted Cuckoo	Dragonflies (*Nationally Critically Endangered*) - Sultan - Lined Forest-Skimmer Mammals (*Nationally Critically Endangered / Globally Vulnerable*) - Smooth-coated Otter

The globally threatened Smooth-coated Otter had also been sighted on the island, as well as in the surrounding waters. Furthermore, 81 species of birds had been observed since the habitat enhancement and restoration efforts. These included uncommon resident species such as the Rufous-tailed Tailorbird and Rufous Woodpecker, two species that are associated with forested areas. During the migratory season, uncommon migrants that had been recorded included Asian Drongo-Cuckoo, Large Hawk-Cuckoo, Chinese Goshawk and Pallas's Grasshopper Warbler.

In addition, the intensive planting of native coastal species on the island had increased the floral species diversity on the island. By ensuring the survival of these plants, Coney Island Park helps to safeguard the native gene pool for these species, hence, protecting and conserving our natural heritage. Increasing the floral species diversity of the island also aids in restoring the island's ecological function, including providing niches or habitats for fauna to forage or as breeding sites.

While woodpeckers were spotted on the island, it was difficult to confirm their utilisation of the nest boxes provided. This could be due to the locality of the nest boxes where the nest boxes were too high up the tree or the vegetation surrounding it were too dense. Nonetheless, the key takeaway is that protecting known natural cavities in trees as nesting sites is the most important conservation measure for these birds, and this could be supplemented by human-made replacement nest boxes.

Coney Island Park long-term monitoring reforestation project

Apart from the habitat enhancement efforts mentioned in the above sections, NParks also embarked on a coastal reforestation project for Coney Island Park. Two plots, totalling 11.1 hectares, adjacent to the mangrove area of the park were dedicated to reforestation (Fig. 23). One of the few long-term monitoring sites in Singapore, Coney Island Park presents a scientific opportunity for NParks to track the success of reforestation efforts over a long period of time.

Fig. 23. Reforestation plots on Coney Island Park.

The main method used for reforestation in Coney Island Park was the maximum diversity method, which is an active approach towards reforestation whereby forest succession is sped up by human intervention (Goosem & Tucker, 2012). Multiple climax species were planted while pioneer species was only a small proportion of the species planted. Moreover, seed dispersal into the island was limited as it was an isolated patch of coastal forest. Applying the maximum diversity method of reforestation helped overcome this limitation as it involved planting as many native coastal species as possible, reducing the need for seed dispersers coming to the island (Goosem & Tucker, 2012).

The two reforestation plots were Casuarina woodlands with little understorey species composition. As such, the objectives of the reforestation project were to (1) improve forest structure, (2) increase canopy cover, and (3) increase understorey species composition. More than 30 species of native coastal plants, totalling more than 8,000 individuals, were planted in the reforestation plots to help meet the project's objectives.

The reforestation plots would be monitored on a long-term basis to track the progress and success of the reforestation, and whether the objectives of the project were achieved. Floral and faunal surveys would be carried out over the years to monitor the change in biodiversity on the island. This would also create engagement opportunities with volunteers, including students and citizen scientists, where they can learn more about the biodiversity found on the island and hopefully, by extension, become stewards of conservation.

Conclusion

A landscape planting palette was specially curated for habitat enhancement efforts on Coney Island Park, which commenced in 2015. The habitat enhancement efforts have shown great success in the protection of the ecological value of native plants, as well as restoring the island's ecological function. This is evident by the increase in the number of fauna and flora species to 157 species of fauna and 86 species of flora that have been observed since the start of habitat enhancement efforts on the island. The planting of critically endangered and presumed nationally extinct floral species also helps to safeguard their native gene pool.

Moving forward, NParks will continue restoring and enhancing the habitats in Coney Island Park to strengthen the island's ecological functions and resilience through improving forest structure and species composition. Biodiversity surveys will also be conducted quarterly to monitor the species diversity on the island.

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CHAPTER 12

Lessons Learnt from Habitat Restoration at Marsiling Park

Eslindah Ismail & Cai Yixiong

Introduction

Marsiling Park, formerly known as Woodlands Town Garden, is a 12.8-hectare park located in the northern part of Singapore. The park comprises 1.26 hectares of mangrove forest, 8.32 hectares of water body and 3.22 hectares of park land. The natural vegetation is made up of four different types of key habitats, namely back mangrove, freshwater stream, grassland, and secondary forest. The site is bordered by the Bukit Timah Expressway (BKE) and Woodlands Centre Road (Fig. 1).

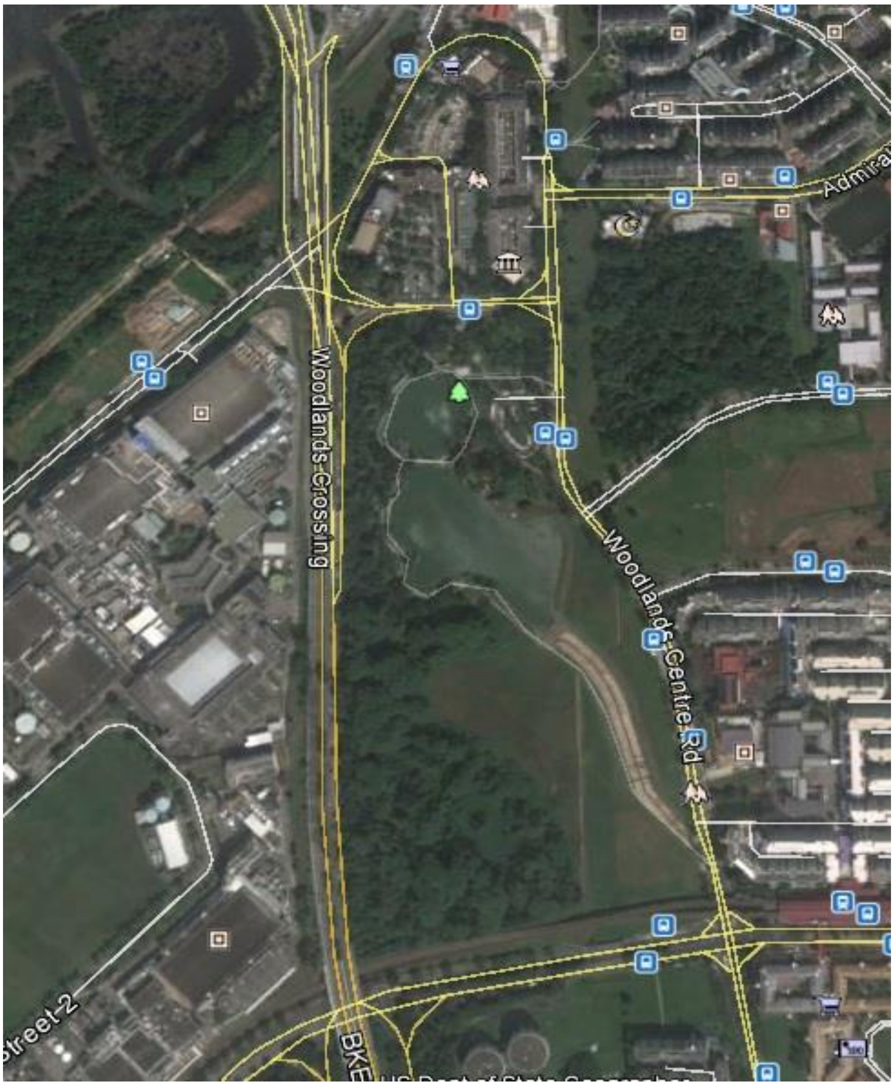
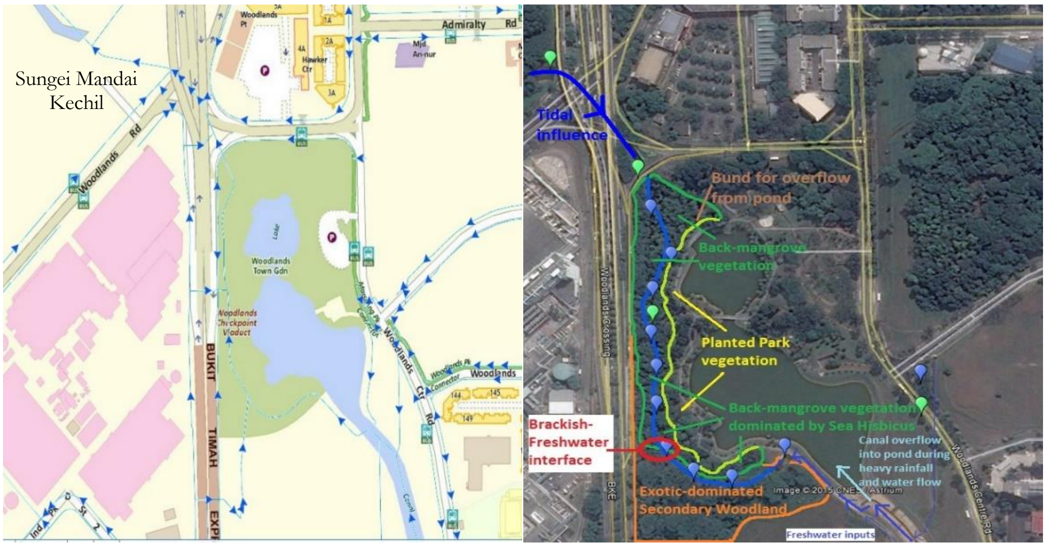


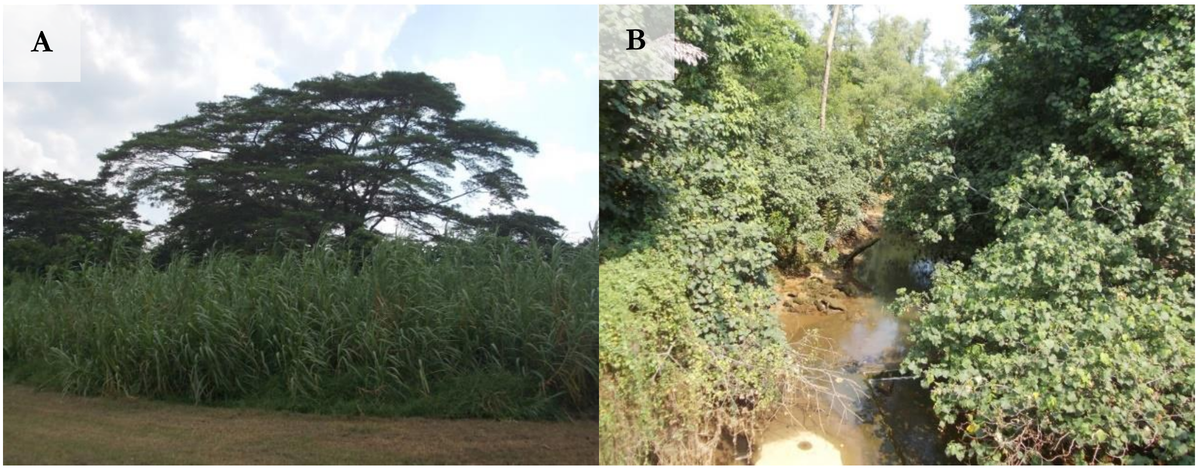
Fig. 1. Google Earth Map showing the location of Marsiling Park. (Image credit: Base map Google Earth@2016)

The mangrove forest is a highly degraded remnant back mangrove (National Parks Board, 2006), with freshwater inputs entering it via the bund for overflow from the PUB storm water pond and lined drains (Fig. 2 & 3). It also includes the uppermost end of the upstream section of Sungei Mandai Kechil, thus it is inundated during high tide. The lower course reaches to Sungei Mandai Kechil and is surrounded by Sungei Mandai Mangrove. The substrate of the site is mainly composed of siliceous sand. Surrounding the back mangrove is grassland, secondary forest, and typical trees in the park (Fig. 4). The section that connects Marsiling Park and Sungei Mandai Mangrove has been turned into a concrete channel as a result of urbanisation (Fig. 5).



Figs. 2. Map of Marsiling Park showing the mangrove forest and its hydrological connections. (Image credit: Base map OneMap@2016; Base map Google Earth@2016, National Parks Board, 2016b)

Fig. 3. Freshwater inputs entering the mangrove forest via the bund for overflow from the pond and lined drains.

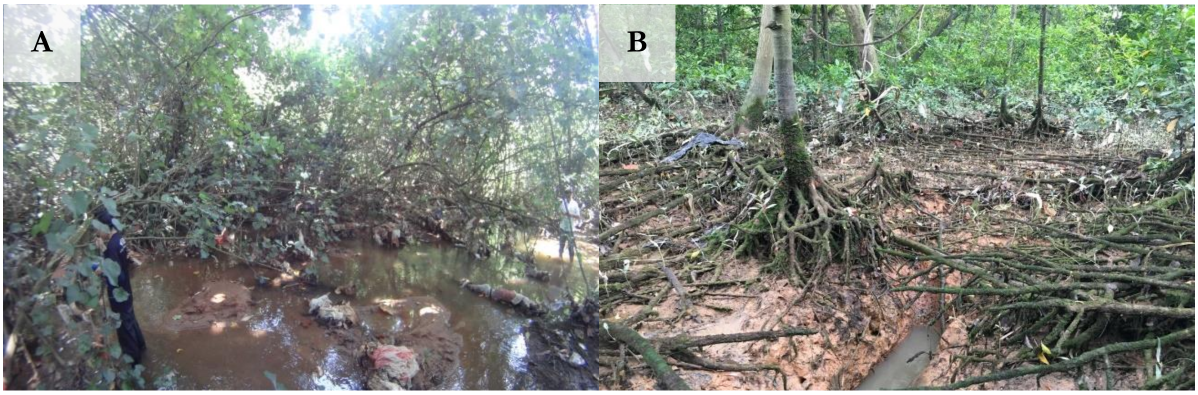


Figs. 4. (A) Grassland park; (B) Secondary forest and trees in the park buffering the mangrove area.

Figs. 5. Part of the Sungei Mandai mangrove that had been concretised into drains.

Threats to the mangrove forest

The mangrove forest faced threats such as the massive inflow of freshwater from the drains and storm water pond that was filled with flotsam during heavy rainfall (Fig. 6A), human disturbance like littering and poaching, and the canalisation of Sungei Mandai Kechil into concrete drains which reduced the inundation by seawater during high tides and thus altered the site's hydrology. This also caused the mangrove habitat to further degrade; the habitat could even disappear eventually in the long term due to the lack of saline water input, which lowered the salinity level of the water in the mangrove site, and could result in the loss of some key species of the flora and fauna. In addition, soil erosion and siltation had slowly built up along the mangrove course due to the changes in hydrology at site (Fig. 6B).



Figs. 6. (A) Flotsam in the mangrove area; (B) Soil erosion observed at the mangrove patch next to the PUB Storm Water Pond. (Photo credit: Cai Yixiong)

An in-depth study of the existing habitats, especially the mangrove of the park, was vital to the understanding of the current conditions and enhancement of the mangrove habitat through restoration of the existing ecosystems from further degradation and future losses. A series of site surveys were conducted to find out the present physical, hydrological and biodiversity conditions of the various habitats found and their impact to the surroundings of the park.

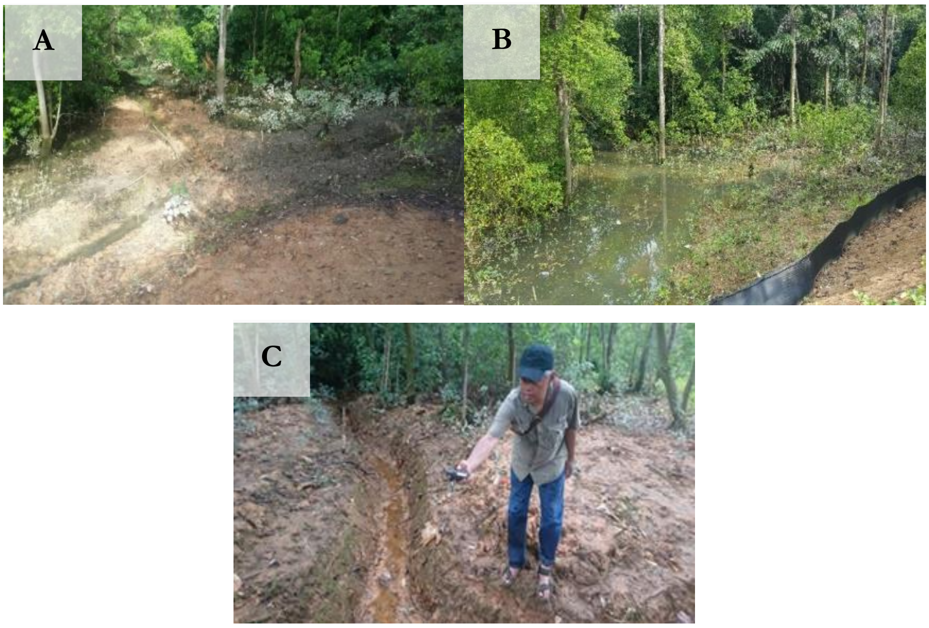
Three main objectives were identified in the study of the habitat enhancement of the mangrove forest at Marsiling Park (National Parks Board, 2016a):

1. To investigate the extent of mangrove habitat degradation and identify the ecological stress and disturbance of the mangrove forest based on the baseline assessment;
2. To reforest and rejuvenate the mangrove forest by changing the profile of the hydrology to prevent further occurrence of soil erosion and working closely with other agencies to mitigate issues of the hydrology and flotsam pollution; and
3. To propose and implement mitigation measures to enhance the ecological and social functions provided by the park.

The reappraisal of the biodiversity on Marsiling Park (National Parks Board, 2016b) revealed and confirmed that the overall species richness for both flora and fauna was still low although a rise in number of terrestrial fauna species had been observed. It was noted, in particular, that no crustacean species was sighted. According to the recent biodiversity assessment, human disturbance and the highly degraded state of the site that had been recognised in 2006 remained valid. Although tidal survey conducted showed evidence of sufficient seawater influence during the spring tidal period, the loss of the locally endangered mangrove tree *Sonneratia caseolaris* and crustacean fauna, as well as changes in aquatic fauna species in the survey area might suggest that the current mangrove site was showing signs of further degradation. The major causes could mostly be the excessive amount of freshwater input from storm water ponds next to the mangrove patch during the monsoon season as well as the overflows coming through several monsoon drains in the upper stream. A high degree of soil erosion observed at the mangrove next to the opening area of the storm water pond might also contribute to the degradation of mangrove habitat as well as the changes of flora and fauna at the site. Further, the current status of the mangrove and its associated fauna in the stream was undermined as the site was heavily covered with Sea Hibiscus (*Hibiscus tiliaceus*) vegetation and littered with flotsam. The biodiversity of Marsiling Park's mangrove would be further impacted when future development of the site was to take place in the near future.

Mitigation measures and enhancements

In order to change the profile of hydrology, the impact of the tides at the site was studied. Channels were excavated and small islets were created in the channels to improve the water flow into the mangrove and mid transitional habitats (Fig. 7A). These channels were monitored to ensure that sea water would flow smoothly into them (Fig. 7B). They were then mapped using GPS technology for use in future studies of the site (Fig. 7C).



Figs. 7. (A) Excavated channels in mangrove; (B) Monitoring of tidal flow at the channels; (C) Mapping of the excavated channels.

In addition, a biweekly maintenance cleansing regime to remove the flotsam, trash, and litter from the stream was executed to ensure that the stream was minimally impacted in the long run. A filtration system was installed at the start of open concrete drain outlet to limit the amount of rubbish getting into the stream (Fig. 8). Public Utilities Board (PUB) also stepped up its cleansing regime in removing the flotsam from the storm water ponds next to the mangrove patch especially during the monsoon season.

Figs. 8. A filtration system at the start of drain channels into the mangrove area.

Fig. 9. Back mangrove saplings along the creek.

The common and easy-thriving mangrove plants had been reintroduced mainly in the habitat enhancement of the mangrove site. The planting of 10% dominant species, namely *Avicennia* spp., *Sonneratia* spp., *Rhizophora* spp., and *Bruguiera* spp., would facilitate the restoration of the mangrove habitat (Fig. 9). The heavy Sea Hibiscus vegetation along the mangrove creek next to the park side had also been removed and those located opposite the park had been pruned to make head room for the new mangrove saplings to nurture and become established at site. Fallen branches were regularly removed so that these saplings could thrive in the long run.

Fig. 10. Plant species adapted to the edges of the creek.

Furthermore, the back mangrove area had been enhanced with plant species that could do well in a low density of brackish water. These plants include Cannonball Mangrove (*Xylocarpus granatum*), Katong Laut (*Cynometra ramiflora*), Mangrove Palm (*Nypha fruticans*), False Lime (*Suregada multiflora*), and White Samet (*Melaleuca cajaputi*). Species such as *Neolitsea zelaynica*, Penaga Laut (*Calophyllum inophyllum*), Chengal Pasir (*Hopea odorata*), and Thick-Leafed Jambu (*Syzygium pachyphyllum*) that adapted to the landward edge of the mangroves were also planted along the periphery to create a natural buffer between the mangrove forest and the park (Fig. 10).

Monitoring to sustain the habitats

Monitoring of the key ecosystems of the park was very vital so that continued survival and sustainability of the habitats in the park could be achieved. A fauna survey of birds, butterflies and dragonflies was highly recommended to be carried out on a biannual basis, with regular transects lined along the mangrove route. One such survey, BioBlitz, recorded a reasonable number of fauna life at the site. With frequent, regular fauna surveys, the patterns and population of the fauna life could be tracked and monitored. A detailed survey on the mangrove site should take place sometime later, for example, two years after the newly planted mangrove saplings had grown up and established. This should then be continued on a yearly basis for the next five years.

As details of the future development plans for its surrounding areas had not been confirmed, any changes to the park site and its adjacent areas should be tracked and recorded so that immediate mitigation measures could be taken to minimise the impact from the development works. In addition, active liaison with the key stakeholders or agencies such as PUB, Immigration and Checkpoints Authority, Land Transport Authority, and Housing & Development Board would be essential so that updates on their works and development plans within the vicinity of the park would be known to NParks as early as possible for mitigation measures to be taken. It is crucial that NParks works closely with these agencies so that a seamless, continuous, and integrated green buffer area could be created between the park and its development site, ensuring that key habitats of ecosystems in the park would be safeguarded and conserved. Careful plant selection would be carried out to create a naturalistic buffer zone and perimeter sites of a wooded park, further facilitating habitat connectivity and movement through the park and its adjacent green coverage within the town area.

Schools within walking distance in the vicinity of the park would also play vital roles in the outreach and education of the biodiversity of the park. Students from the schools could help raise awareness and importance on the key habitats of the ecosystems and their values in the life cycles. Interactive guided walks, interesting outdoor class lessons and activities, informative interpretative signboards were some ways that would encourage young children and teenagers to learn about the biodiversity of Marsiling Park.

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CHAPTER 13

Coastal Protection Synergy with Mangrove Restoration in Pulau Tekong

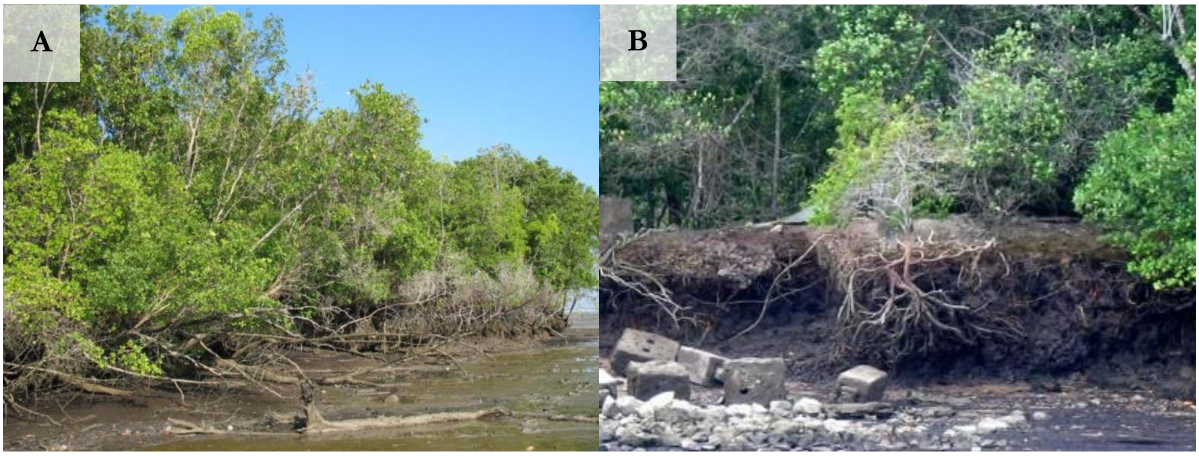
Yang Shufen, Ang Hui Ping & Lena Chan

Introduction

The 92 hectares of mangroves on the northeastern coastline of Pulau Tekong represent one of the largest tracts of pristine mangrove forests remaining in Singapore, which include Sungei Buloh Wetland Reserve and Pulau Ubin. It supports a rich diversity of plants and animals (Fig. 1), and has some of the rarer mangrove species such as *Bruguiera parviflora* (Endangered), *Aegiceras corniculatum* (Endangered) and *Kandelia candel* (Critically Endangered). It is also home to the only natural population of Tumu Putih (*Bruguiera sexangula*), which is a true mangrove species previously thought to be extinct in Singapore, and the Mangrove Pitta (*Pitta megarhyncha*), which is a locally critically endangered bird species. Due to its high biodiversity significance, the area has also been designated as a Nature Area under Urban Redevelopment Authority's (URA) Special and Detailed Control Plan.

Fig. 1. Rich flora and fauna biodiversity of Pulau Tekong mangrove.

Studies conducted in 2009 and 2010 showed that the scouring of the mangroves had occurred, resulting in erosion and habitat degradation of the mangrove forest. The affected 1.9 kilometres of coastline had resulted in landward recession ranging between 1 to 9 metres in one year (Fig. 2A & 2B). This meant a total of about 10,000 square metres area of land, equivalent to that of a football field was lost in that year. This resulted in land loss, tree deaths and habitat degradation. Hence, immediate actions were needed to halt the erosion.



Figs. 2. (A & B) Scouring of the coastline resulted in erosion and around 1,000 mangrove trees were assessed at risk of falling.

Planning and trials

Studies were conducted to quantify the severity and extent of the erosion along the coastline. About 1.65 km of the 3-km coastline required urgent intervention and many mangrove trees were at risk of falling. High wave energy in the area was identified as the root of the problem and a solution was desperately needed to stop the coastline from receding further. This was when the National Parks Board (NParks) thought of restoring the mangrove habitat via a hybrid approach – the planting of mangrove saplings and installation of coastal protection measures for the eroding coastline. It was a novel idea, although the exact way of a successful implementation had to be worked out.

With that, NParks took the lead and coordinated a cross-disciplinary team that included a diversity of experts from public agencies and private consultants to discuss solutions and conduct trials and studies. The Housing & Development Board (HDB) was appointed as the managing agent based on its vast experience in marine works; Surbana International Consultants Pte Ltd, environmental consultants from DHI Water & Environment, marine construction specialists from Koon Construction & Transport Co Pte Ltd and ecologists/horticulturists from Uvaria Tide Pte Ltd were appointed for various components of the project based on their domain expertise (Fig. 3).

Fig. 3. Consultation with many agencies and consultants from various disciplines to carry out the trials.

During the brainstorming sessions, many different options and potential solutions were tabled. To optimise the success rate of this project, a one-year pilot field trial was carried out based on these potential solutions and the conceptual design. This was followed by intense discussions between NParks and the various experts and stakeholders to review and re-design the project based on the findings obtained from the field trial.

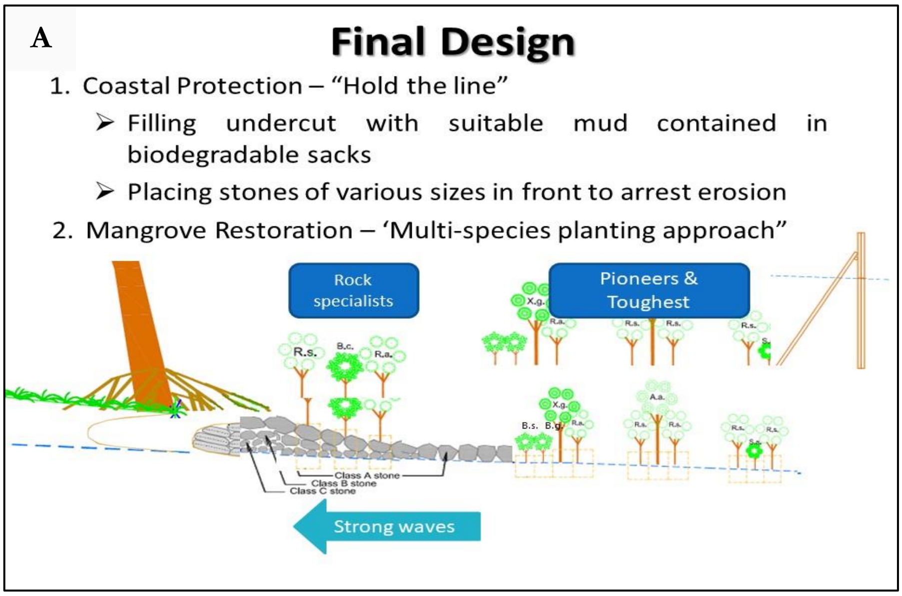
The journey to find an optimum feasible solution

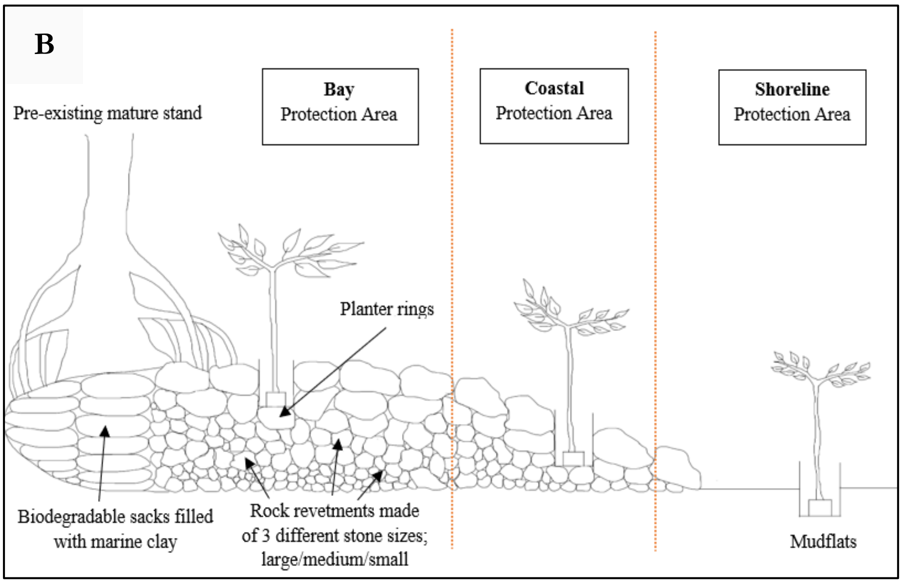
The initial design intent was to plant mangroves throughout to provide a natural protection along the entire coastline. To ensure that the solution fits the local environment, we conducted literature surveys, baseline hydraulic modelling studies, and a pilot field trial to test three things, i.e., (1) securing saplings using biodegradable coir logs or mats, (2) sediment types, and (3) different rates of survival for the mangrove species. The results of the one-year field trial indicated that the very strong local wave conditions, coupled with storm events, resulted in the inability of the coir logs and mats to be secured for the successful establishment of mangroves and sediment stabilisation Invaluable data on the mangrove species zonation based on water inundation levels helped to determine and identify the multiple mangrove species planting scheme. The field trial was crucial as we learnt that more factors had to be taken into consideration. We further observed and studied other areas in Singapore where mangroves grew on rocky substrates and documented the elevation and species. An innovative hybrid approach using both 'hard' and 'soft' engineering solutions, which included the construction of low rock revetments interspersed with active planting of mangrove saplings in biodegradable planter pots, was finally adopted based on science and studies of the local conditions (Fig. 4).

To achieve coastal protection, the first approach was the 'hold-the-line strategy'. This 'hard' solution or the coastal protection approach aimed to arrest the erosion caused by the scouring waves, by filling the undercut with marine clay sourced from the nearby dredges and tested their environmental qualities to match the local substrate conditions. To ensure that the mangroves were prevented from falling further, biodegradable sacks filled with marine clay off-site were placed beneath the eroding berm to support the overhang and provide a suitable substrate for the continued growth of the existing mangrove trees. The marine clay was contained in biodegradable sacks so that the sediment would not be washed away with each tidal cycle causing deterioration of water quality. Stones of various sizes were then placed along the coast, forming a low rock revetment, to reduce the impacts of breaking waves and arrest erosion.

The 'soft' solution or the mangrove restoration approach aimed to restore the mangrove habitat and mitigate the wave action through multi-species planting of native mangrove saplings, instead of the conventional single species planting. All 13,500 saplings used in the project were grown from propagules collected from all over Singapore to retain our native gene pool for mangrove trees. The selection of mangrove species was based on NParks' extensive surveys and observations of mangrove species around Singapore and their substrate types, supplemented with findings on species suitability and zonation from the field trial carried out at a site in the vicinity of the restoration work.

An Environmental Impact Assessment (EIA) was carried out to review the final design and proposed works to be carried out with the guiding principle that the works would have no or minimal impact on the environment. This was demonstrated in the various measures stipulated such as having a resident ecologist, marking out specific mangrove trees of interest, and filling all sacks of marine clay off site to minimise suspended sediments.





Figs. 4. (A & B) Diagrams of the rehabilitation site layout. Erosion was arrested by using a combination of 2 strategies; 1. Biodegradable sacks filled marine clay were placed under eroding berm, 2. Rock revetments made up of three different classes (sizes) of stone were carefully arranged to form a barrier against wave effects. Mangrove saplings were planted within biodegradable planter rings, placed in between the rocks (bay protection area and coastal protection area) and in the mudflats (shoreline protection area).

Implementation & Environmental Monitoring and Management Plan (EMMP)

The construction phase commenced on 11 October 2010 and ended on 20 September 2011. Throughout the entire construction period, works were stringently supervised to ensure minimal impact to the existing environment. Environmental consultants from DHI were tasked to do the EMMP to ensure that the project continued to make no or minimal impact to biodiversity and the physical environment. (Fig. 5)

Fig. 5. Three main components of the EMMP involving the monitoring of 1) Existing mangroves, 2) Newly planted mangrove saplings and 3) Natural recruitments.

Besides ensuring that the construction works caused minimal damage on-site, surveys of existing mangroves were also conducted to monitor the health of the mangroves and to establish whether there had been any detectable changes or impacts as a result of the changes to the pattern of tidal exchange within the mangrove habitat and across the shoreline in comparison to the baseline survey results. The surveys provided useful and relevant additional information about the biodiversity and ecology of the existing mangroves in Pulau Tekong. The existing mangrove survey comprised the following components:

i) Measurement of sediment characteristics
ii) Monitoring and tagging of rare species along the shoreline
iii) Assessment of the mangrove forest structure

Newly planted mangrove saplings were also monitored to determine the health condition, survival and growth rates of different sapling species over time and location across the project area. Some of the monitoring parameters included:

i) Survival of the saplings (alive or dead)
ii) Health condition for the living saplings (1. Healthy, 2. Stressed, 3. Re-sprouting, and 4. No leaves)
iii) Leaf chlorophyll content (enabling estimate of leaf nitrogen through the use of correlation curves)
iv) Plant growth parameters (height, stem diameter and number of leaves, branches and roots)

Natural recruitment of propagules and saplings along the site were also monitored to develop an understanding on the patterns of recruitment of mangrove seedlings within the structure, including species diversity abundance and development stage, in relation to vertical and horizontal distribution across the shoreline and natural phonological patterns for each mangrove species. This information would help in the designing and enhancement of certain characteristics of future shoreline stabilisation structures that would help in natural recruitment.

Continuous monitoring for sustainability

After the completion of the construction phase, another three rounds of monitoring were conducted in 2012, 2013 and 2016. The continuous monitoring was essential to assess the survival rate of the remaining saplings that were planted, as well as to determine the capacity of the rock revetments in promoting the natural recruitment of mangroves. While the survival rate (3.7%) of the remaining saplings was lower than expected, it clearly illustrated that planting at the right bathymetry level was crucial in ensuring greater survivability of the mangrove saplings. On the other hand, the natural recruitment monitoring showed that there were a large number of recruits of varying species found in the project area. This suggested that the shoreline stabilisation structure provided an avenue for natural recruitment to occur. Some trends were apparent at the site where morphological characteristics of the shoreline and the existence of a cove-like bay also appeared to play some role in facilitating greater levels of recruitment and survival of mature seedling at the site. Interestingly, the natural recruitment did not apply to the mangrove saplings only. During the last monitoring done in 2016, other marine organisms were found inhabiting within or outside the planter rings (Fig. 6).

Figs. 6. Marine organisms found inside the empty planter rings at the shoreline protection area.

Conclusions and lessons learnt

2021 marked the tenth anniversary of the Pulau Tekong coastal protection and mangrove restoration project. A field trip on 26 July 2023 indicated that there were no fallen mangroves, the mangroves were thriving healthily, and young mangroves were establishing, attesting the successful implementation of the coastal protection and mangrove restoration.

Monitoring the progress of this initiative was important as the results had far-reaching implications that could be used by management agencies planning future mangrove conservation projects in Singapore, or in the immediate region, as a guide to nature-based mangrove restoration and enhancement.

The key lessons learnt included:

1) It is essential to include multiple species of mangroves preferably from sources in the original site or its vicinity in restoration projects as they emulated that of natural ecosystems and ensured ecological resilience as insurance against the effects of climate change.
2) Determining the best location across the intertidal zone in which to plant different mangrove species is crucial as the re-creation of natural mangrove shorelines by incorporating a relatively flat and sheltered profile at higher bathymetries would ensure the greater survival of the planted saplings and to promote natural recruitments. A modification of the slope profile of the rock revetment would improve the survival, recruitment rate and natural accretion.
3) More experimental localised planting studies with larger sample sizes should be carried out to better understand the different species and their responses to the restored or rehabilitated environment and to more accurately assess the optimum bathymetry for planting each species. This should be done with a study of their accretion rate which would be key to combating the challenge of sea level rise and climate change.

This project had successfully test-bedded a unique approach, that was the first of its kind in Singapore and possibly in the world, to address the problems of eroding mangroves using nature-based solutions. It demonstrated Singapore's balanced approach towards development and commitment to environmental sustainability. This project showed that the protection or restoring of our shorelines could be implemented with a hybrid approach of leveraging on hard structures with the incorporation of the 'soft' elements through the planting of multiple species of mangroves. It also provided evidence that with the restoration of ecosystems, recruitment of biodiversity would occur as long as there were gene stocks in the vicinity. This innovation resulted in an ecologically sound, aesthetically pleasing and less intrusive appearance, that enhanced the native biodiversity and increased adaptive resilience against sea level rise. The project fulfilled its objectives of adopting a holistic, integrated, multi-disciplinary and innovative approach to solving complicated environmental problems while taking into consideration multi-stakeholders concerns. It showcased the synergies and positive results of close-knit collaborations and the need for cross-disciplinary exchanges to surmount the originally thought-to-be wicked challenges.

Acknowledgements

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CHAPTER 14

High-relief Artificial Reefs at Sisters' Islands Marine Park

Chou Loke Ming, Santosh Srirangam, John Kiong & Karenne Tun

Introduction

Artificial reef history dates back to the 18th century with early attempts aimed at exploiting the fish aggregating ability of structures placed in the sea. Japanese fishers sunk derelict vessels, American fishers sunk wooden logs, and subsistence fishers of developing countries deployed coconut frond structures, all with the common purpose of improving fish catch (White *et al.*, 1990). Since then, artificial reef development has expanded geographically and for increasing purposes including the rehabilitation of degraded reefs and marine ecotourism promotion. A vast range of materials is used, and various designs, configurations, dimensions, and scales are adopted. The contribution of artificial reefs as well as artificial structures in the marine environment to enhance marine biodiversity has been well documented (Chou, 2021).

Singapore lost more than half of its natural reefs to coastal development and various reef restoration initiatives have been implemented since the 1980s (Ng *et al.*, 2016), mainly to improve the condition of existing reefs. Relevant to Singapore's context is the development of new reefs to supplement those that are permanently lost. New reefs can be effectively induced by large, full water-column structures that present vertical aspects of the natural reef slope profile. Such purpose-built structures mimicking natural reef systems were deployed in JTC Corporation's Reef Garden Project at the Sisters' Islands Marine Park in 2018. The purpose of this project is to transform an open water environment above a barren seafloor into a rich, reef-associated biodiversity zone. In terms of size, this is the largest artificial reef structure deployed in Singapore. In terms of vertical reach through the water column, perhaps it is also the highest relief structure in the region, apart from decommissioned oil rigs left to function as artificial reefs.

Project development

The purpose-built reef structure was conceptualised and designed by HSL Constructor Pte Ltd, the National Parks Board (NParks) and JTC Corporation (JTC), with valuable inputs from marine interest groups and academe. Technical design aspects were considered in engineering conditions that favourably support marine life. A key challenge of this project was to select a suitable location for the reef structures in Singapore's tightly zoned sea space. The waters of Small Sister's Island were chosen for JTC's reef project implementation after a vigorous site selection process in consultation with various government agencies.

DHI, commissioned by JTC, performed an Environmental Impact Study (EIS) to determine the impact of these artificial reef structures on various aspects including the seabed, ecology, and navigational safety (DHI, 2016). The EIS identified slight to moderate negative impact on suspended sediment, underwater noise, navigational safety, recreation, macrobenthos and wind waves. However, HSL and JTC followed a strict mitigation and management protocol proposed by DHI to nullify any negative impacts that may arise during and after construction and launching of the artificial reef units.

Another important aspect of this project was that structural stability could be attained without piling but instead using the structure's weight and wide base coupled with steel anchors and counterweights at the base (Fig. 1). This effectively minimised seabed disturbance. The structures were pre-fabricated off-site on land and then lowered slowly and carefully to the seabed (Fig. 2).

Fig. 1. Complete unit of artificial reef structure ready for installation. (Photo credit: Srirangam Santosh Kumar)

Fig. 2. Top section of artificial reef structure being lowered into the sea. (Photo credit: Srirangam Santosh Kumar)

Structural design that mimics reef slopes

A sloping configuration for the artificial reef structures was decided on earlier to be a good representation of the natural reef slope profile in Singapore. Each structure resembled two reef slopes placed back-to-back resulting in a basic A-frame module with a wider base narrowing to the apex. The surface area at the upper section was increased by incorporating rectilinear, fibreglass mesh panels at different levels to reduce shading and allow sediment to fall through. It was also necessary to maximise the surface area for coral growth especially in the upper section where sunlight was adequate. The multi-level configuration took advantage of the varying amount of sunlight penetration through the top six metres of the water column, which was essential for coral survivability and growth. The structure had to be sufficiently tall (12 metres, which was comparable to a three-storey landed house) to optimise the sunlight penetration zone. Interstitial spaces within each artificial reef structure unit as well as the modularity of units allowed for a diverse biological community to develop on and around them. Water flow through the units was not hindered and the modular arrangement of the units reduced alteration of prevailing current flows. The units, however, could be arranged in patterns that would help to reduce wave energy on exposed shores and function as the first line of coastal defence.

Choice of material was another important consideration. The main frame was cast in concrete with rough surfaces to favour coral growth. Small rocks excavated from the Jurong Rock Caverns project were encrusted on the concrete frame to increase textural complexity, necessary for encouraging the settlement and development of diverse biological communities. Apart from the fibreglass mesh panels, fibreglass pipes were also used to reduce overall weight of the structure and to add another type of microhabitat to the artificial reefs. The pipe's curved surface also prevented sediment accumulation. Fibreglass is known to favour coral attachment based on research in Singapore waters (Ng *et al.*, 2017).

Corals from development locations have in the past been translocated to natural reefs, particularly the more degraded ones, but space is running out on those reefs. With their high relief, the artificial reef structures provide new space suitable for such corals displaced from other development sites. Close to 2,000 coral colonies from various locations have since been transplanted to the structures. NParks and coral reef researchers identified different coral genera to be translocated. The introduction of these transplanted coral colonies will enhance the overall marine biodiversity of the Sisters' Islands Marine Park.

Biodiversity development is currently being monitored through a few research projects. These are formulated to establish the natural colonisation patterns of the structures by fish and benthic species, and growth and survival of transplanted corals. The results of these investigations will influence modifications in the design of new structures to further increase their effectiveness.

High-relief artificial reefs can provide numerous ecosystem services. Mimicking natural reef slopes, they are effective for enhancing marine biodiversity, especially of the open sea. They therefore have the potential of expanding Singapore's reef ecosystem. This approach is valuable as reef restoration can only improve the health of existing reefs without much possibility of areal expansion. It is also useful in Singapore's limited but heavily utilised sea space. The eight units of the high relief artificial reef structures provide 1,000 square metres of space for the development of corals and reef-associated biota. Apart from enhancing marine biodiversity, these structures can be placed in configurations to absorb wave energy and, therefore, provide a coastal defence service.

Acknowledgements

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minded engineering and construction companies, research organisations and universities, to contribute to the cause of protecting coastlines from global warming and sea level rise.

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CHAPTER 15
Habitat Enhancement for Slope Stabilisation at Kent Ridge Park

Soh Ze Bin, Mohammad Roslee Ali & Holly Siow

Introduction

Kent Ridge Park is part of the Southern Ridges, which is located in the southwest of Singapore and includes Mount Faber Park, Telok Blangah Hill Park, HortPark, and Labrador Nature Reserve. The vegetation type found in this park is largely Adinandra belukar ('belukar' is the Malay word for 'secondary forest'), characterised by disturbed young secondary forest with a canopy dominated by Tiup Tiup (*Adinandra dumosa*). Given the history of disturbance within this forest, the canopy is more open, the forest is much drier, and the soil quality is much poorer than a mature rainforest. The forests within the Southern Ridges are also quite isolated from mature forest patches that could act as a seed source. This has resulted in the floristic diversity remaining at a very low level.

When the slope along the mountain biking trail in Kent Ridge Park failed in December 2015, there was an immediate need for it to be stabilised. Given Kent Ridge Park's status as a nature area and a popular site for nature lovers, this slope failure was seen as an opportunity by the National Parks Board (NParks) to increase the biodiversity of this site by habitat enhancement after the works had been completed, instead of merely re-turfing the slope (which is the standard practice for newly stabilised slopes). The planting palette was chosen to include plants found in mature forest areas including those in Singapore's Central Catchment Nature Reserve. Care was taken to ensure that plants chosen would be able to survive in harsh open conditions characteristic of the post-stabilisation environment, could establish on sloped terrain, and were sustainable from an operational and maintenance point of view. For this reforestation project, we aimed to increase the floristic diversity of this area, so as to provide a seed source to the surrounding forest, thus allowing it to progress to a more mature ecological succession stage.

As such, the objectives of the Kent Ridge Park slope habitat enhancement project were as follows:

1. Creating slope stability, especially at the steepest portion of the slope
2. Restoring ecosystem diversity and structure from a degraded site
3. Ensuring sustainability through frequent and consistent monitoring and management of the planted area

Methodology

How the incident happened

In early December 2015, a section of a southward facing slope within the Kent Ridge Park Mountain Bike Trail failed and a landslide resulted (Fig. 1). The affected area covered a total area of approximately 0.3 hectares (3,000 square metres) (Fig. 2), measuring about 100 metres long and 30 metres wide with an elevation difference of about 30 metres. The area had a dense vegetation of predominantly secondary forest species such as *Adinandra dumosa*, *Cyrtophyllum fragrans*, *Dillenia suffruticosa*, and *Macaranga heynei*.

The incident was detected on 11 December 2015 but subsequent investigations showed that the mountain bikers had first spotted the slope failure as early as 5 December 2015. Several supporting facilities were dislodged as a result. NParks closed off the mountain bike trail, and a slope consultant and a slope stabilisation contractor were engaged to survey the extent of the affected area and propose methods to stabilise the area.

Fig. 1. Slope failure at Kent Ridge Park, Mountain Bike Trail in December 2015.

Fig. 2. Approximately 3,000 square metres of area was affected.

Slope engineering and slope stabilisation method

Waterproof canvas sheets were laid over the bare exposed areas to protect them from further water erosion and to minimise water seepage into the ground (Fig. 3).

Figs. 3. Large canvas sheets were laid over to prevent the saturation of soil, which might lead to further slope failure.

Mackintosh test and borehole rigs were installed on site for soil investigation to gather geotechnical information on the subsoil conditions at the site for the design of stabilisation methods. However, immediate mitigation measures were put in place to safeguard the site in view of the progressive erosion observed on site, compounded by the rain which was typical of the weather pattern at the end of the year.

After analysing the results, the final stabilisation method chosen for the area was the soil nail with grid beam method (Fig. 4). Soil nails each measuring up to 12 metres in length were inserted perpendicularly into the ground. Subsequently, concrete grid beams were cast around each of the nail in the shape of a square which were filled up by soil and turf. In addition, the previous bike trail had to be reinstated. Each of the grid beam measured around 3 metres by 3 metres to provide sufficient planting space for small trees, where possible, and shrubs. The depth of soil added was roughly 0.3 metre for the grid beam section.

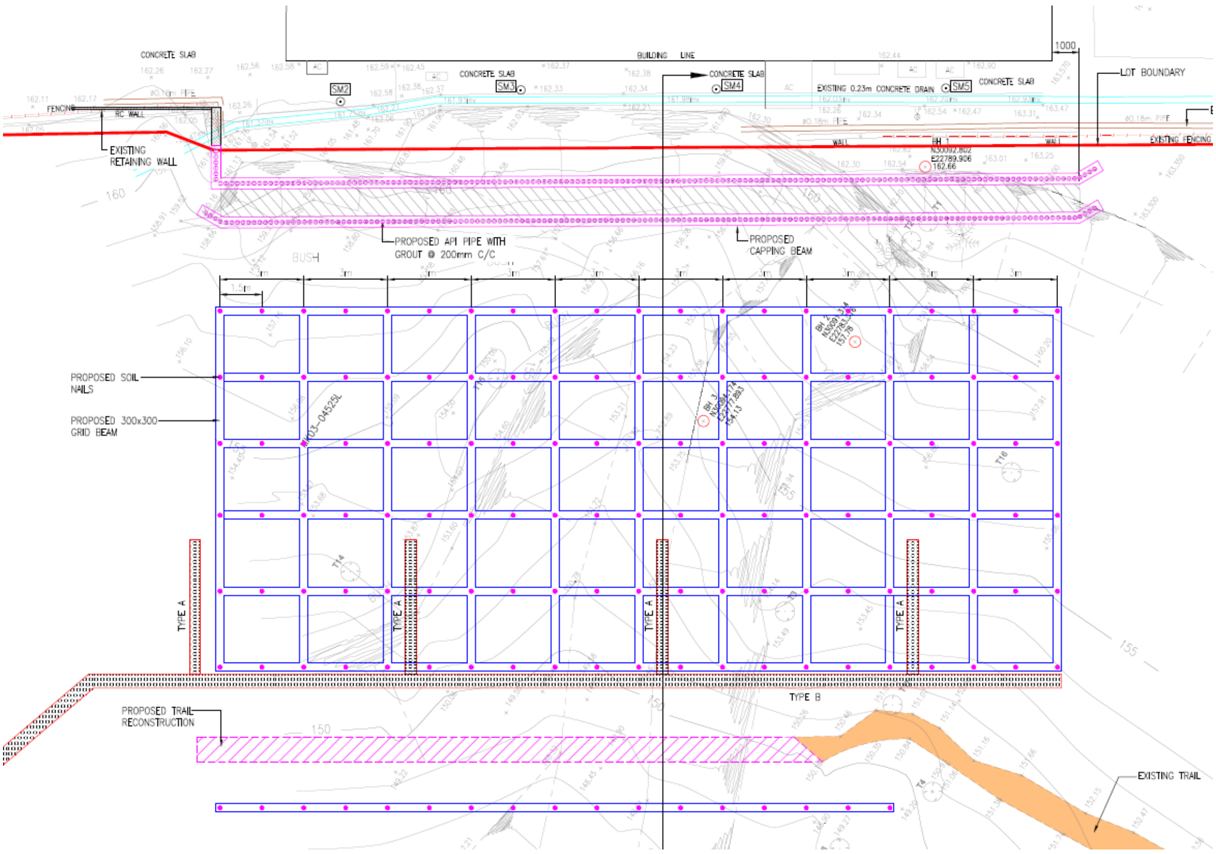


Fig. 4. Grid beams layout plan.

Timeframe

- December 2015 to February 2016: Immediate mitigation measures, soil investigation and submissions
- March 2016 to December 2016: Slope stabilisation (through the soil nail with grid beam method), drain constructions and trail reinstatement (Fig. 5)
- January 2017 to February 2017: Soil top-up, planting and establishment period (Fig. 6–10)

Fig. 5. Construction of grid beams in October 2016.

Fig. 6. Backfilling of soil in January 2017.

Fig. 7. Planting of turf at end January 2017.

Fig. 8. Planting of native shrubs (*Melastoma malabathricum*) on Area 1 in February 2017.

Fig. 9. Differentiation of planting at Area 1 (shrubs) and 2 (trees and larger shrubs) in February 2017.

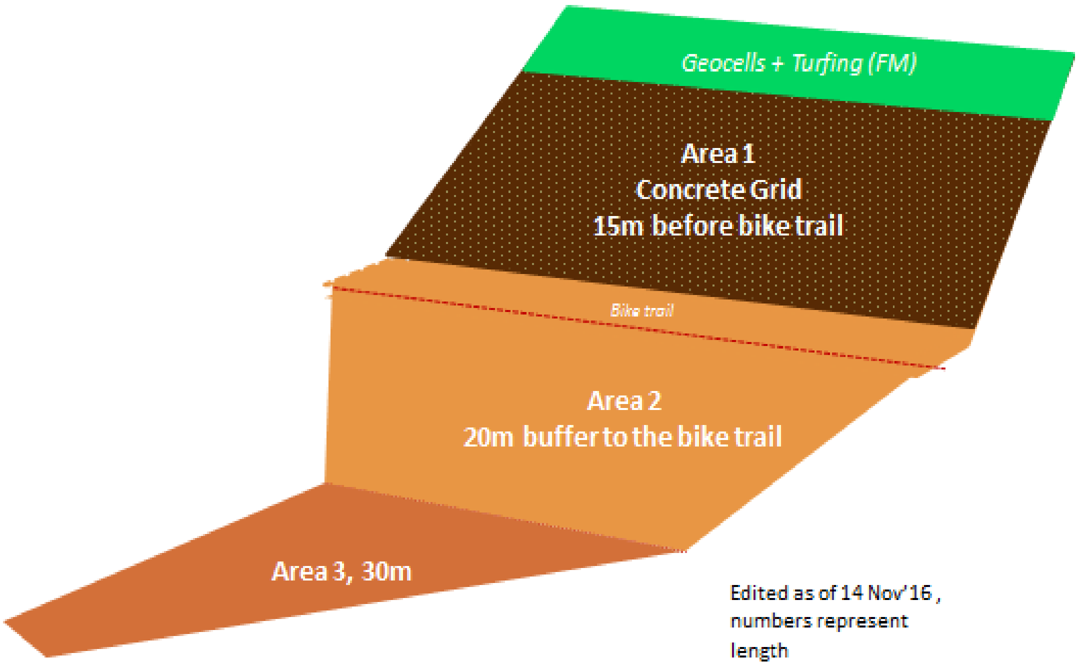


Fig. 10. The 3 distinct slope areas, with reference to the indicative mountain bike trail track.

Formation of a workgroup formed for the project

A habitat enhancement workshop was organised on 10 October 2016 by National Biodiversity Centre (NBC) and the Centre for Urban Greenery and Ecology (CUGE). A workgroup, comprising eight members from different NParks divisions, was formed to look at enhancing habitats at potential sites within parks with a range of biodiversity found in Singapore. Within Kent Ridge Park, the slope was also identified to be a case study with actual implementation as the slope stabilisation works were nearing completion.

The group held two investigation site visits to survey the surroundings and document the existing environment conditions, vegetation and fauna observed (Fig. 11). Following the visit, the group worked with the data and eventually came up with a planting palette that was suitable for the various soil depths found at the different sections (Table 1).

Fig. 11. A site visit for a rapid survey in February 2017.

Planting palette

Table 1: Planting palette for slope stabilisation habitat enhancement

Area 1	Area 2	Area 3
Melastoma malabathricum (plant extensively)	*Dillenia suffructicosa* (minimal)	*Koompassia malaccensis*
Leea rubra	*Ficus grossularioides*	*Shorea curtisii*
Ardisa crenata	*Ficus aurata*	*Alstonia angustiloba*
Ardisia elliptica	*Caryota mitis*	*Archidendron clypearia*
Cheilocostus speciosus	*Adinandra dumosa*	*Archidendron jiringa*
Ficus deltoidea	*Ploiarium alternifolium*	*Syzigium zeylanicum*
Tristellateia australasiae	*Rhodamnia cinerea*	*Horsfieldia irya*
Rhodomyrtus tomentosa	*Macaranga heynei*	*Parkia speciosa*
	Macaranga hypoleuca	*Sindora wallichii*
	Macaranga gigantea	*Palaquium obovatum*
	Bauhinia semibifida	*Macaranga bancana*

Results and monitoring

Monitoring

In February 2017, a mixture of six species of trees and shrubs (Table 2), numbering about 70, were planted at Area 2 and 3 where the deeper soil depth allowed for larger trees to be planted. The soil was also from the original site. They were planted at approximately 2-metre gaps to allow for subsequent growth.

Table 2: Tree species that were planted on Feb 2017.

1) *Horsfieldia irya*
2) *Horsfieldia polyspherula*
3) *Ploiarium alternifolium*
4) *Rhodamnia cinerea*
5) *Sindora wallichi*
6) *Syzygium zeylancium*

Survival rate

During the survey of January 2019, many of the original species that were planted survived although some did not establish well (Fig. 12). This could be due to the soil conditions where they were planted in. The soil at Kent Ridge Park was tested and found to be acidic with a pH level of 5 to 5.5. The lack of substantial organic matter on the ground surface, as only young trees were planted, was not enough to improve the soil condition and pH level.

Fig. 12. Most of the tree saplings survived, as seen during a visit to the site in February 2017.

Height, outlook, and appearance

Some of the trees such as *Horsfieldia irya*, were observed to be doing better than others such as *Sindora wallichii*, where they were showing signs of yellowing in their leaves which could be caused by a variety of health problems such as nutrient deficiency in the soil and lack of water (partially due to the drier weather conditions in January 2019).

Presence of Spontaneous Recruitment

Several spontaneous species such as *Muntingia calabura* and *Adenanthera pavonina* were observed to have established in the plot (Annex A). The seeds of these species were likely to be dispersed by birds which was a positive sign, indicating that fauna had visited the area. A single specimen of *Cecropia pachystachya*, a pioneer tree species that could spread rapidly and invasively in disturbed forests, was also observed. It was removed to a depth of 0.1 metre below surface so that as much of its root system was removed to inhibit its regeneration.

Site utilisation

Butterflies, including the Common Mormon (*Papilio polytes romulus*) and Chocolate Pansy (*Junonia hedonia ida*), and odonata species including the Common Parasol (*Neurothemis fluctuans*) and Scarlet Grenadier (*Lathrecista asiatica*), were frequently seen fluttering in this site. The fauna sighted so far had been common species that were also found in other parts of Kent Ridge Park. It is likely that more species will utilise the site as vegetation establishes and grows in height and density.

Subsequent management of area

The habitat enhancement site, located more than 400 metres from the start of the mountain bike trail, is within the Adinandra belukar secondary forest. Quarterly maintenance programmes to remove invasive species such as *Mikania micrantha*, *Cecropia pachystachya* and *Acacia auriculiformis* was needed for the planted species to establish and grow quickly. The slopes were left to self-regenerate after the initial assistance given at the beginning.

Results of the habitat restoration and enhancement initiatives

Figures 13 and 14 show how habitat restoration and enhancement works can transform a slope failure and degraded site to a stable slope with enriched niches for flora and fauna, leveraging on nature-based solutions. This project demonstrates that nurturing a suitable environment would lead to self-recruitment of flora and fauna, hence, leading to a long-term regeneration of natural ecosystems. Monitoring the site would enable NParks to learn how ecological succession occurs in parks that are near highly urbanised areas and how the state of a park can become closer to that of more pristine natural ecosystems.

Fig. 13. View from top (towards the east) photographed in 2019.

Fig. 14. View from top (towards the south) photographed in 2019.

Annex A

January 2019 – Observations of spontaneous seedlings.

Muntingia calabura

Stachytarpheta indica

Ficus grossularioides

Adenanthera pavonina

Adenanthera pavonina closeup

Cecropia pachystachya

January 2019 – Conditions of original trees/shrubs planted in February 2017.

Cheilocostus speciosus

Syzygium zeylanicum

Sindora wallichi

Horsfieldia irya

CHAPTER 16

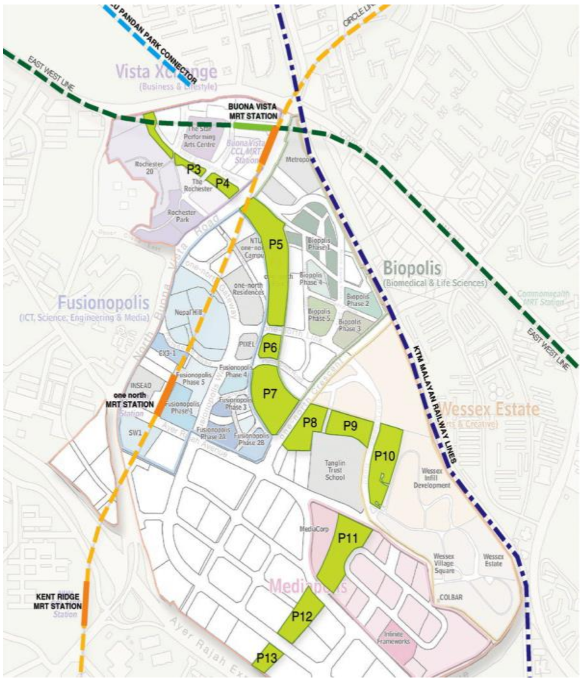
Habitat Enhancement in Small Parks in Highly Urbanised one-north

Eslindah Ismail

Introduction

Many of the land parcels that have been re-zoned as park land are open, under-utilised, and unattractive sites. These sites could be remnant land that is located adjacent to commercial buildings, former construction sites or storage areas, or land with disturbed vegetation and forested area. One case study that the National Parks Board (NParks) had innovatively designed and transformed the sites into creating habitats for wildlife and park spaces was the one-north Park, Rochester West and East, and Fusionopolis North and South parcels.

These four land parcels formed part of the 16-hectare park that stretched across the entire length of one-north district in the heart of Singapore's up-and-coming research and business district (Fig. 1).



Land Parcel (P)	Name
P5 (Opened Oct 2005)	one-north Park: Biopolis
P11 (Opened Dec 2015)	one-north Park: Mediapolis
P3 (Opened June 2016)	one-north Park: Rochester West
P4 (Opened June 2016)	one-north Park: Rochester East
P6 (Opened June 2016)	one-north Park: Fusionopolis North
P7 (Opened June 2016)	one-north Park: Fusionopolis South

Fig. 1. A map showing the location of the parks and habitats for wildlife in one-north Park.

Besides developing green pockets for recreational outdoor activities in one-north, NParks had put in place the principles of environmental sustainability in habitat creation for fauna, particularly for birds and butterflies in Fusionopolis North and South.

Fusionpolis North and South

At Fusionopolis North, a butterfly garden was created by planting specially selected butterfly host plants that attracted and provided food for butterflies, caterpillars, and other insects. Brightly coloured flowering shrubs, grasses, and wildflowers such as the Peacock Flower (*Caesalpinia pulcherrima*), Golden Dewdrop (*Duranta erecta*), Common Lantana (*Lantana camara*), and Common Sendudok (*Melastoma malabathricum*) stood out as the main highlights of this garden (Fig. 2).

Fig. 2. A Tawny Coster (*Acraea terpsicore*) lands on the purple flowers of the Golden Dew Drop (*Duranta erecta*), a butterfly-attracting plant.

At least 10 species of butterflies including the Lime Butterfly (*Papilio demoleus malayanus*), Common Tiger (*Danaus genutia genutia*), and Blue Pansy (*Junonia orithya wallacei*) had been spotted gliding gracefully among flowering plants during clear and sunny mornings. Five species of bees such as the Asian Honeybee (*Apis cerana*) and Shiny Wing Carpenter Bee (*Xylocopa auripennis*) had also become residents here!

A rain garden was also created for this 0.58-hectare park, planted with specifically chosen wildflowers and grasses that aided natural filtration of stormwater runoff within the park (Fig. 3). This had evolved into a habitat for butterflies, dragonflies, bees, birds, and aquatic wildlife.

Fig. 3. The rain garden provides home to the fauna.

Retaining the existing vegetation, including the remnant secondary forests, Fusionopolis South was enhanced with multi-tiered and diverse vegetation, specifically biodiversity-attracting plants to create habitats for fauna (Fig. 4).

Fig. 4. A boardwalk cutting through the secondary forest has also been installed at Fusionopolis South to allow visitors to get closer to nature.

To attract birds to the park, NParks enhanced the plot with trees such as the Weeping Fig (*Ficus benjamina*), Malayan Wild Cherry (*Muntingia calabura*), Tembusu (*Cryptophyllum fragrans*), and Saga Tree (*Adenanthera pavonina L.*). Such trees are attractive to many bird species, serving as food sources. Bird lovers would be able to spot species such as the Common Flameback (*Dinopium* *javanese*), Long-tailed Parakeet (*Psittacula longicauda*), and Pink-necked Green Pigeon (*Treron vernans*). Despite its small size of 2.43 hectares, more than 15 species of birds had been sighted in this park.

Conclusion

These parks in one-north may be small (i.e., less than 3 hectares), but with thoughtful and well-planned habitat enhancement designs, they provide biodiversity-rich areas for people to connect with nature. Strategically located in built-up areas, these green spaces contribute to meeting the target of 100% of Singapore's residents being within a 10-minute walk or 400 metres from a park or nature reserve by 2030. People can experience and connect with the urban biodiversity in the one-north community within a short distance from their work and home places!

CHAPTER 17

The HortPark Bee Trail: Habitat Enhancement and Education for Bees in Singapore

Zestin Soh & Jacqueline Chua

Introduction

Bees play an integral role to Singapore's ecosystems. As major pollinators of native and cultivated plants, bees maintain the genetic diversity of wild plant populations and support the productivity of urban edible gardens. However, the general public in Singapore is largely unaware about native bee diversity, and the fear of bees is common among Singaporeans. This is in spite of the fact that the city-state is home to a rich diversity of about 140 bee species (Ascher *et al.*, 2022; Soh & Ascher, 2020), most of which are docile and pose little risk to people. In addition to a paucity of local outreach efforts for bees, targeted efforts to conserve bee diversity, such as habitat enhancements, are relatively novel in Southeast Asia. Our objectives for this project were thus to:

1. Develop a locally relevant, evidence-based bee planting palette for Singapore using data on bee foraging and nesting;
2. Pilot the bee planting palette together with artificial nest boxes to conserve a rich diversity of native bee species, in conjunction with providing interpretative signs and programming for public education;
3. Partner with the community to further address the knowledge gap and sustain bee conservation efforts.

Methods

Planting palettes for bees

Planting schemes to support butterflies are well documented and established in Singapore, but very little similar information is available for bees. Like butterflies, adult bees and their offspring rely almost entirely on plants for sustenance. While several species in the tropics are known to be generalists (e.g., the honey bees, *Apis* spp.), a large proportion of species exhibit foraging preferences for pollen and require suitable flowering plants to persist. In addition to food, twig-nesting small carpenter bees and reed bees (*Ceratina* spp. and *Braunsapis* spp. respectively), stingless bees (Tribe Meliponini), and leafcutter bees (*Megachile* spp.) rely on particular plants for nesting sites and/or nest-building materials (e.g., leaves, resin).

To build our planting palette, we compiled bee-plant interaction data from field surveys across parks in Singapore, published research papers (e.g., Soh & Ngiam, 2013; Ascher *et al.*, 2019), museum reference collections (e.g., the Lee Kong Chian Natural History Museum), and photographs taken by citizen scientists (e.g., nation-wide BioBlitz). Plant species with greater frequency of interactions with bees at multiple sites were scored as more effective bee-attracting plants. We also recorded plant species that were used by bees for nesting material or nesting sites, and collaborated with the National University of Singapore to document examples (Soh *et al.*, 2019). These were combined to create the first planting palette that contains forage and nesting plants, tailored to supporting native bee diversity for Singapore (see Appendix 1).

Bee hotels

Several species of solitary, cavity-renting bees of the family Megachilidae naturally nest in pre-existing cavities in the environment, such as in dead wood. However, such natural nesting sites are often scarce in urban areas and managed parks. Artificial nest boxes used to supplement the lack of nesting sites and support populations of these solitary bees are known as "bee hotels". Bee hotels have been widely implemented in farms, parks, and urban areas across North America and Europe to bolster solitary bee populations, but have not been tested widely in Southeast Asia. Solitary wasps, which play a beneficial ecological role as natural enemies to herbivorous insects, may also nest in bee hotels. Crucially, unlike the social honey bees which tend to sting when their hives are disturbed, solitary bees and wasps are docile and do not defend their nests, preferring to flee instead. Thus, from a public risk management perspective, bee hotels were assessed to be safe to be sited in areas of human activity. We therefore sought to implement bee hotels and test their effectiveness as habitat enhancement in Singapore.

HortPark Bee Trail

A hub for novel horticulture research and initiatives, HortPark was found to be an ideal site to trial the bee habitat enhancement initiatives. HortPark's bee fauna had also been very well surveyed relative to many areas in Singapore, being one of the study sites of pollinator research by Soh & Ngiam (2013). We decided to leverage HortPark's collection of garden plots by implementing the bee habitat enhancement features as a trail across three existing thematic gardens: the Native Garden, the Butterfly Garden, and the pollinator-friendly Edible Garden. The inclusion of these three gardens was an opportunity to showcase the bee-supporting flora associated with three distinct habitat contexts in Singapore (Table 1; Fig. 1–3), and concurrently highlight the diverse roles that bees play in Singapore for broader educational value.

We reviewed the three gardens along the trail, and found that most of the existing flora was suitable for bees. The trail was enhanced further through additional plantings to enhance the density and diversity of bee-supporting plants.

Table 1. Gardens of the Bee Trail.

	Description	**Educational opportunity about bees**	**Bee-supporting flora**
Native Garden	A collection of native trees and shrubs from Southeast Asian lowland forests.	Highlights the role of bees in supporting the natural ecosystem and its native biodiversity.	▪ *Ardisia elliptica* [F] ▪ *Dendrolobium umbellatum* [F+N] ▪ *Melastoma malabathricum* [F] ▪ *Premna serratifolia* [F+N] ▪ *Pluchea indica* [F] ▪ *Leea indica* [F+N] ▪ *Leea rubra* [F+N] ▪ *Kleinhovia hospita* [F]
Butterfly Garden	A mix of introduced and native shrubs and climbers that attracts butterflies.	Highlights how bee-friendly landscaping may be conducted in parks, gardens, and urban settings, particularly alongside existing enhancements to support butterflies.	▪ *Leea indica* [F+N] ▪ *Rotheca myricoides* [F+N] ▪ *Antigonon leptopus* [F+N] ▪ *Stachytarpheta indica* [N]
Edible Garden	Plots of edible vegetable and fruit crops	Highlights the role of bees in supporting edible gardening in Singapore.	▪ *Talinum triangulare* [F] ▪ *Luffa aegyptiaca* [F] ▪ *Citrullus lanatus* [F] ▪ *Psophocarpus tetragonolobus* [F] ▪ *Solanum melongena* [F] ▪ *Capsicum anuum* [F] ▪ *Ocimum basilicum* ▪ *Clitoria ternatea* [F+N] ▪ *Moringa oleifera* [F]

[F] – Forage plants

[N] – Plants which provide nesting sites or nesting material for bees

Figs. 1. Bee-attracting flora in the Native Garden. (Photo credit: Zestin Soh)

Figs. 2. Bee-attracting flora in the Butterfly Garden. (Photo credit: Zestin Soh)

Figs. 3. Bee-attracting flora in the Edible Garden. (Photo credit: Zestin Soh)

Coupling interpretative signage with nest boxes

We designed eight frames for installing bee hotels along the trail, each with a roof to keep out the rain. The frames allowed the bee hotels to be modular, making it easy to re-orientate the blocks, and add or remove materials for maintenance if required. Each frame also doubled as educational signage, with a side featuring a poster containing pictures, text and a QR code to an online trail guide. These frames were then positioned strategically along the trail as markers to highlight interesting bee-related features in each of the three thematic gardens (Fig. 4).

Seven frames were installed with bee hotels. Inside the eighth frame, we placed a box hive of Valdez's Stingless Bees (*Tetragonula valdezi*) that had been rescued from an abandoned fridge. This harmless native species is common and naturally occurring at HortPark. We also set a disused upturned plant pot containing a hive of the same stingless bee species along the trail. Both the bee hotels and the stingless bee hives allowed visitors to safely observe bees that are lesser known and often overlooked by the public.

Fig. 4. Frame installed with bee hotel showing the interpretative sign. (Photo credit: Zestin Soh)

Monitoring

To test the effectiveness of the bee planting palette and bee hotels in supporting bees, we conducted observational surveys to record bee diversity along the HortPark Bee Trail twice a month.

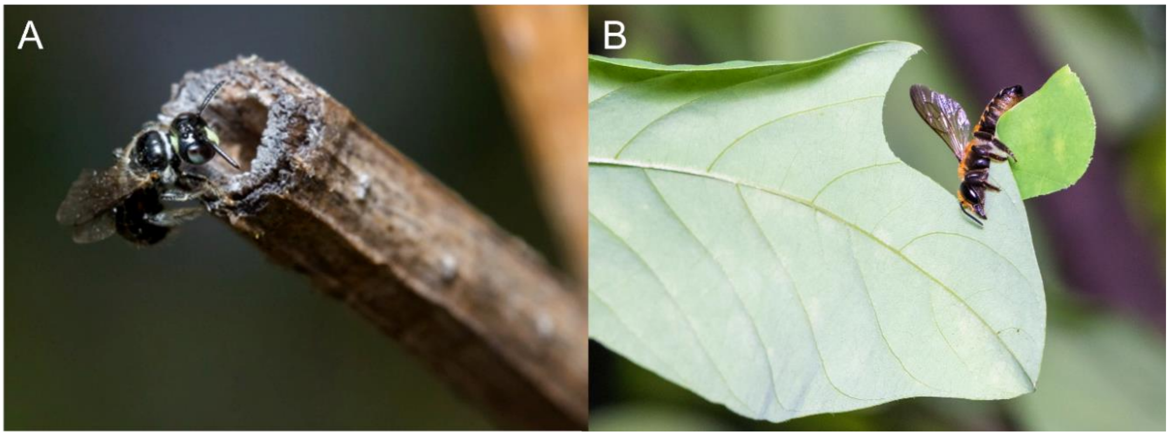
Results and discussion

Launch and public outreach

The trail was launched on 15 September 2018, and members of the public were invited to the event. Students of Jurong West Primary School were trained as station guides for the bee trail to engage the public and share with them facts about native bees and the bee-supporting plants. Over 200 visitors attended the event and walked the trail. Since then, guided walks by volunteer guides at the trail have been conducted quarterly, and the venue is used for workshops on bee species identification.

Bee diversity and newly recorded species

Over the monitoring period along the Bee Trail between 15 September 2018 to 22 September 2019, we recorded a rich diversity of 31 bee species along the trail. This included seven new bee records for the park, bringing the recorded diversity for HortPark to 40 species (see Appendix 2). For comparison, only 20 bee species were recorded over seven months in HortPark in 2012 (Soh & Ngiam, 2013). The vast majority of the species recorded was seen visiting flowers. This included the newly recorded rare *Ceylalictus communis* and *Nomia thoracica*, which were observed visiting *Pluchea indica* and *Leea rubra* respectively. We also observed *Braunsapis hewitti* nesting within *Rotheca myricoides* (Fig. 5) and *Megachile* bees cutting foliage plants along the trail, demonstrating that the nesting plants were used.



Figs. 5. Examples of bees using plants for nesting: (A) Hewitt's Reed Bee (*Braunsapis hewitti*) nesting in a pithy stem of *Rotheca myricoides*; (B) Broad-headed Leafcutter Bee (*Megachile laticeps*) gathering a piece of leaf from *Dendrolobium umbellatum*. (Photo credit: Zestin Soh)

Bee hotel occupancy

Occupants were seen in only four of the seven bee hotels along the trail over the one-year monitoring period. These active hotels were under semi-shade, whereas the three empty hotels were under full sun – a crucial learning point for future siting of bee hotels. Nonetheless, the four active bee hotels were utilised by seven species of Megachilid bee for nesting (Fig. 6), four of which are new bee records for HortPark. The most significant bee found was *Anthidiellum smithii* (Fig. 6G), a rare solitary bee species that was last recorded for Singapore in 2015 in the vicinity of Bukit Timah Nature Reserve (Soh & Soh, 2020). We also observed and documented for the first time two rare instances of cleptoparasitism by native cuckoo bees: the first instance being *Coelioxys confusus* (Fig. 6E) on *Megachile tricincta* (Fig. 6A), and second being the rare *Euaspis polynesia* (Fig. 6F) on the uncommon *Megachile fulvipennis* (Fig. 6D). These observations demonstrate that bee hotels in Singapore may not only support common species (such as *Megachile laticeps* and *Megachile disjuncta*), but rare ones as well.

Figs. 6. Bee occupants of the Bee Hotels along the HortPark Bee Trail: (A) Golden-bellied Leafcutter (*Megachile tricincta*); (B) Broad-headed Leafcutter (*Megachile laticeps*); (C) Disjunct Resin Bee (*Megachile disjuncta*); (D) Orange-winged Resin Bee (*Megachile fulvipennis*); (E) Confusing Sharp-tailed Bee (*Coelioxys confusus*); (F) Asian Chilli-tail Bee (*Euaspis polynesia*); (G) Smith's Rotund-Resin Bee (*Anthidiellum smithii*). (Photo credit: Zestin Soh)

Conclusion and future directions

The HortPark Bee Trail was developed with the intention of trialling and showcasing contextualised habitat enhancement for bees and providing a unique venue for public education on Singapore's bee diversity. Bee hotels were installed along the trail amongst bee-supporting plants, together with educational signage and a link to an online trail guide. Trail users can observe bees nesting in the bee hotels, or foraging for food among the bee-attracting plants. The trail is safe, as it only promotes flower-visitation by honey bees and nesting of solitary bees and stingless bees. Since its launch, over 30 bee species had been observed foraging and nesting along the trail.

The monitoring of the trail's bee hotels had provided insights in informing how bee hotels should be set up to maximise usage by bees. The information had been used in a new bee hotel programme for community gardens, launched by Community-in-Bloom. All participating gardens would receive a bee hotel that they could set up and monitor to provide more data on bee habitat enhancement.

Fig. 7. A bee hotel provided to community gardens. (Photo credit: Jacqueline Chua)

Data on bee-plant interactions were compiled to ensure that the planting palette was evidence-based and locally relevant. Information on these bee-supporting plants was also included in a published guidebook to the bees of Singapore (Soh & Ascher, 2020), as well as in the latest expansion of the NParks Flora & Fauna Web (FFW), an online database for plants. The database is growing and constantly being updated with ongoing research. It is our hope that with all the available information on bee-supporting plants, landscapers will have quick and easy access to a wide selection of suitable plants to create successful pollinator-friendly gardens by habitat restoration and enhancement across Singapore.

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Appendix 1: Bee-supporting planting palette.

Highly attractive bee forage plants

Common name(s)	**Scientific name**	**Honey Bees**	**Stingless Bees**	**Leafcutter Bees**	**Large Carpenter Bees**	**Digger Bees**	**Nomias**	**Sweat Bee**	**Cloak-and-Dagger Bees**	**Reed Bees**	**Small Carpenter Bees**
Long-leaved Beauty Berry	*Callicarpa longifolia*	+	+			+	+			+	
Red Leea & Common Tree-vine	*Leea rubra & Leea indica*	+	+			+	+	+		+	+
Buas-buas	*Premna serratifolia*	+	+	+				+	+	+	
Senduduk, Singapore Rhododendron	*Melastoma malabathricum*				+	+	+			+	+
Spicate Eugenia	*Syzygium zeylanicum*	+	+	+	+		+	+		+	
Petai Laut	*Dendrolonium umbellatum*			+			+				
Simpoh Air	*Dillenia suffruticosa*	+	+		+	+	+			+	+
Yellow Cow Wood	*Cratoxylum cochichinense*	+	+	+	+		+				+
Seashore Ardisia	*Ardisia elliptica*		+		+	+	+				
Nipis Kulik, Blue Strawberry Flowers	*Memecylon caeruleum*			+		+	+				
Gelam	*Melaleuca cajuputi*	+	+					+			
Kemunting, Rose Myrtle	*Rhodomyrtus tomentosa*				+	+	+	+		+	
Snakeweed	*Stachytarpheta* spp.	+			+	+	+		+	+	
Hairy Beggarticks	*Bidens pilosa*	+	+	+		+	+	+	+	+	+
Blue Glory Bower	*Rotheca myricoides*		+		+		+			+	
Coral Vine, Honolulu Creeper	*Antigonon leptopus*	+	+	+	+		+			+	+
Dark-eyed Turnera	*Turnera subulata*	+	+		+	+		+		+	+
Chinese Violet	*Asystasia gangetica*	+	+	+		+	+	+	+	+	+
Golden Bells	*Tecoma stans*	+			+	+			+	+	+
Buah Cheri, Malayan Cherry	*Muntingia calabura*	+	+	+	+		+	+		+	+
String Bush	*Cordia cylindrostachya*	+		+	+		+		+		
Fiddlewood	*Citharexylum spinosum*	+			+		+			+	+
Winged Bean, Four-angled Bean	*Psophocarpus tetragonolobus*			+	+		+				
Basil	*Ocimun* spp.	+	+	+		+		+	+	+	+
Waterleaf, Surinam Purslane	*Talinum triangulare*	+	+	+		+		+		+	
Sponge Gourd	*Luffa aegyptiaca*	+	+		+		+	+			+

Note: Green: native; Blue: introduced & non-edible; Orange: introduced & edible crops.

Plants with leaves used by leafcutter bees

Common name	Scientific name
Petai Laut	*Dendrolobium umbellatum*
Yellow Cow Wood	*Cratoxylum cochinchinense*
Candlebush	*Senna alata*
Common Bauhinia	*Phanera kockiana*
Indonesian Bay Leaf	*Syzygium polyanthum*

Plants with pithy-stems suitable for twig-nesting small carpenter bees and reed bees

Common name	Scientific name
Peacock Flower	*Caesalpinia pulcherrima*
Buas-Buas	*Premna serratifolia*
Blue Glory Bower	*Rotheca myricoides*
Common Tree-vine	*Leea indica*
Coral Plant, Fountain Bush	*Russelia equisetiformis*
Pink Mussaenda	*Mussaenda erythrophylla*

Appendix 2: Bees of HortPark

Common name	Scientific name
Black Dwarf Honey Bee	*Apis andreniformis*
Red Dwarf Honey Bee	*Apis florea*
Asian Honey Bee	*Apis cerana*
Giant Honey Bee	*Apis dorsata*
Valdez's Stingless Bee	*Tetragonula valdezi*
Orange-legged Combed-Sweat Bee	*Lasioglossum deliense*
White Combed-Sweat Bee	*Lasioglossum albescens*
Wandering Combed-Sweat Bee	*Lasioglossum vagans*
Tooth-legged Small Carpenter	*Ceratina dentipes*
Lieftinck's Small Carpenter	*Ceratina lieftincki*
Perforatrix Small Carpenter	*Ceratina perforatrix*
Hewitt's Reed Bee	*Braunsapis hewitti*
Puang Reed Bee	*Braunsapis puangensis*
Broad-handed Carpenter	*Xylocopa latipes*
White-cheeked Carpenter	*Xylocopa aestuans*
Yellow-and-black Carpenter	*Xylocopa flavonigrescens*
Cerulean Carpenter	*Xylocopa caerulea**
Sunda Banded-Digger	*Amegilla andrewsi*
Koroton Banded-Digger	*Amegilla korotonensis*
Himalayan Cloak-and-Dagger Bee	*Thyreus himalayensis*
Thai Epaulette-Nomia	*Pseudapis siamensis*
Red-waisted Grass-Nomia	*Lipotriches ceratina*
Indomalayan Pronged-Nomia	*Nomia incerta*
Felt-topped Nomia	*Nomia thoracica**
Striped Nomia	*Nomia strigata*
Iridescent Nomia	*Nomia iridescens*
Blood Bee species	*Sphecodes* sp.

*New records for HortPark since launch of the Bee Trail

Appendix 2: Bees of HortPark *(Cont'd)*

Common name	**Scientific name**
Kuala Lumpur Steppe Bee	*Ceylalictus communis**
Smith's Rotund Resin Bee	*Anthidiellum smithii**
Asian Chilli-tail Bee	*Euaspis polynesia**
Orange-belled Leafcutter	*Megachile subrixator*
Broad-headed Leafcutter	*Megachile laticeps*
Shadow-winged Resin Bee	*Megachile umbripennis*
Golden-bellied Leafcutter	*Megachile tricincta**
Disjunct Resin Bee	*Megachile disjuncta*
Orange-winged Resin Bee	*Megachile fulvipennis**
Tuberculate Resin Bee	*Megachile tuberculata*
Confusing Sharp-tailed Bee	*Coelioxys confusus*
Woodborer Bee	*Lithurgus* sp.
Armoured Resin Bee	*Heriades othonis*

*New records for HortPark since launch of the Bee Trail

CHAPTER 18

Pond-edge Planting for Habitat Enhancement and Improvement of Park Users' Experience in Punggol Park

Isnarti Jamari

Introduction

Punggol Park underwent redevelopment by the National Parks Board's Parks Development branch in 2014, which included the re-landscaping of the sparsely planted pond edge to enhance the biodiversity of the pond. The project was completed in 2016. However, the newly introduced aquatic plants for the re-landscaping were badly attacked by animals.

The habitat enhancement project was introduced in 2017 to enhance the biodiversity in Punggol Park. The objectives were to increase the population of plant species along the pond edge and increase the population of odonate species.

Methods

A trial planting was done in 2016 to identify the badly attacked aquatic plant species (Lam, 2016). The aquatic plant species planted in 2014 are listed in Appendix 1.

The plants were closely monitored after a few days. It was observed that *Cyperus haspan* and *Pontederia cordata* were badly attacked by Apple Snails (Phylum Mollusca) (Quek *et al.*, 2014) and Terrapins (*Trachemys scripta elegans*) (Lam, 2016). These identified species were not able to survive the attack of the predators.

The species planted in 2014 that survived, such as *Cyperus alterfolius* and *Thalia dealbata*, were added to the existing ones (see Appendix 2). Other species such as *Cymbopogon citratus* and *Typha latifolia* were introduced to the pond. These newly added plants were planted on the opposite site of the pond between November 2017 and May 2018 (Fig. 1). These plants were monitored until they became established; this took about four weeks (see Appendix 2). No drastic loss of plants was found after the establishment period (Fig. 2 & 3).

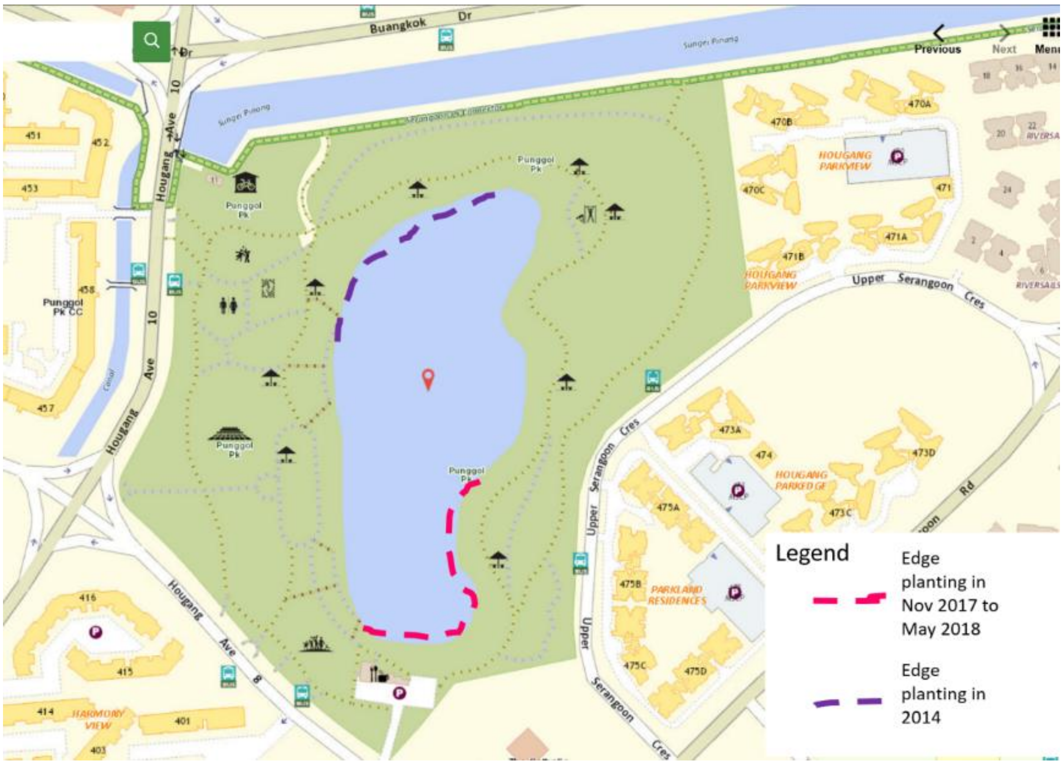

Fig. 1. Locations of planting in 2014 and new planting from November 2017 to May 2018.

Fig. 2. The sparsely planted pond edge in October 2017. (Photo credit: Isnarti Jamari)

Fig. 3. View of the same pond edge taken in August 2018 after enhanced planting. (Photo credit: Isnarti Jamari)

Results and monitoring

Ten odonate species were recorded in the baseline survey done in 2010 (see Appendix 3) (Ngiam *et al*., 2010). After the habitat enhancement in 2018, a survey was carried out at the edge of the pond. Sampling was conducted during cloudy weather on 8 August 2018 from 1045 hrs to 1150 hrs. The survey methodology used for odonate species was to walk around a pond/wetland slowly and visually identify the odonates. Eight dragonfly and damselfly species were sighted (see Appendix 4).

Although the number of species observed was fewer compared to those in 2010, a new species, the Common Scarlet (*Crocothemis servilia*) was added to the species list found at Punggol Park pond. This could be due to the time of and the weather conditions during the survey.

Two more surveys were conducted in the last quarter of 2018. One was conducted at the later part of the day to increase the probability of detecting other species that foraged during those hours.

The results of the surveys carried out in 2018 and subsequently are presented in Appendix 5.

The number of species was fewer for the late afternoon survey on 12 October 2018 than during the earlier hour of the day. This could be due to the cloudy weather when the survey was conducted. There were no new species recorded too. However, on the sunny morning of 20 December 2018, two new species, White-barred Duskhawk (*Tholymis tillarga*) and Blue Percher (*Diplacodes trivialis*), were sighted. These species were not recorded during the baseline survey in 2010.

Conclusions and lessons learnt

Punggol Park pond has the potential to be a suitable habitat for odonates. Addition of other types of aquatic plants like emergent and sub-emergent plants will enhance the pond habitat further and therefore enhance the species diversity and population size of odonates in Punggol Park pond. Looking at the records, the weather plays an important role on the species sighted during the survey.

Acknowledgements

I would like to thank Siti Rafe'ah Omar who conducted the odonate survey in 2018, and Yvonne Chee and Low Kok Seong who were directly involved in the development in 2014. Idamurni Jamari kindly edited this paper.

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Appendix 1: Aquatic plants species planted in 2014 Redevelopment Project

Common name	Scientific name
Umbrella Sedge	*Cyperus alternifolius*
Dwarf Papyrus Sedge	*Cyperus haspan*
-	*Lepironia articulata*
Pickerel Weed	*Pontederia cordata*
Powdery Alligator Flag	*Thalia dealbata*
Alligator Flag	*Thalia geniculata*
Narrow-leaf Cattail	*Typha angustifolia*
Dwarf Cattail	*Typha haspan*

Appendix 2: Aquatic plants species planted in 2018

Common name	Scientific name
Umbrella Sedge	*Cyperus alternifolius*
Powdery Alligator Flag	*Thalia dealbata*
Narrow-Leaf Cattail	*Typha angustifolia*

Appendix 3: List of dragonfly and damselfly species in baseline survey recorded in August 2010

Common name	Scientific name
True Dragonfly/Anisoptera	
Emperor	*Anax guttatus*
Common Flangetail	*Ictinogomphus decoratus*
Trumpet Tail	*Acisoma panorpoides*
Common Amberwing	*Brachythemis contaminata*
Common Parasol	*Neurothemis fluctuans*
Variegated Green Skimmer	*Orthetrum sabina*
Common Chaser	*Potamarcha congener*
Banded Skimmer	*Pseudothemis jorina*

Appendix 3: List of dragonfly and damselfly species in baseline survey recorded in August 2010 *(Cont'd)*

Common name	Scientific name
Damselfly/Zygoptera	
Blue Sprite	*Pseudagrion microcephalum*
Common Bluetail	*Ischnura senegalensis*

Appendix 4: List of dragonfly and damselfly species recorded on 8 Aug 2018

Common name	Scientific name
Common Amberwing	*Brachythemis contaminata*
Banded Skimmer	*Pseudothemis jorina*
Variegated Green Skimmer	*Orthetrum sabina*
Blue Sprite	*Pseudagrion microcephalum*
Common Bluetail	*Ischnura senegalensis*
Common Flangetail	*Ictinogomphus decoratus*
Common Scarlet	*Crocothemis servilia*
Common Parasol	*Neurothemis fluctuans*

Appendix 5: List of dragonfly and damselfly species recorded on 12 Oct 2018

Common name	Scientific name
Common Parasol	*Neurothemis fluctuans*
Common Amberwing	*Brachythemis contaminata*
Blue Sprite	*Pseudagrion microcephalum*
Common Flangetail	*Ictinogomphus decoratus*
Banded Skimmer	*Pseudothemis jorina*
Common Bluetail	*Ischnura senegalensis*
Variegated Green Skimmer	*Orthetrum sabina*
Common Scarlet	*Crocothemis servilia*

Appendix 6: List of dragonfly and damselfly species recorded on 20 Dec 2018

Common name	Scientific name
Variegated Green Skimmer	*Orthetrum sabina*
Common Amberwing	*Brachythemis contaminata*
Common Flangetail	*Ictinogomphus decoratus*
Banded Skimmer	*Pseudothemis jorina*
White-barred Duskhwak	*Tholymis tillarga*
Blue Sprite	*Pseudagrion microcephalum*
Common Bluetail	*Ischnura senegalensis*
Common Scarlet	*Crocothemis servilia*
Blue Percher	*Diplacodes trivialis*

CHAPTER 19

Habitat Restoration Resulting in the Establishment of Hampstead Wetlands Park

Evelyn Chong & Khairullah Abdul Razak

Introduction

In a wetland incongruous with its surrounding industrial buildings, wildlife enthusiasts can be seen gathered on a boardwalk, under the shade of lush Rain Trees, comparing their latest observations of wildlife seen in the area. The friendly enthusiasts would kindly point out to curious onlookers, if they asked, the interesting biodiversity which can be appreciated at Hampstead Wetlands Park.

The usual resident bird species attracting the enthusiasts at the park are the Oriental Pied Hornbill (*Anthracoceros albirostris*), Banded Woodpecker (*Chrysophlegma miniaceum*), Common Flameback (*Dinopium javanense*), Coppersmith Barbet (*Psilopogon haemacephalus*), Buffy Fish Owl (*Ketupa ketupu*), and White-throated Kingfisher (*Halcyon smyrnensis*). When the migratory season arrives, the acrobatic Blue-tailed Bee-eaters (*Merops philippinus*) swoop across the wetlands, delighting many photographers with their aerial hunting moves. Other visitors include the Lesser Whistling Duck (*Dendrocygna javanica*) and Asian Openbill (*Anastomus oscitans*).

With Hampstead Wetlands Park's long list of biodiversity (which is usually associated with larger parks), one would be surprised that this park is a small 3.23-hectare constructed wetland. Jointly developed by JTC Corporation and the National Parks Board (NParks), the rustic green sanctuary provides rest and recreation for the workers from the Seletar Aerospace Park and residents in the vicinity.

The land which Hampstead Wetlands Park currently sits on was previously part of the Seletar Base Golf Club, which was closed in 2007. Its lower-lying area gradually collected run-off and the surrounding vegetation became overgrown until the park was developed in 2019.

Geography

How did Hampstead Wetlands Park attract biodiversity, despite its small size, and unlikely location within an industrial zone?

At first glance, it might appear that Hampstead Wetlands Park is an isolated spot of green amidst an otherwise industrial area. The park is located in the northern region of Singapore, on the eastern side of Lower Seletar Reservoir, and unconnected to Nature Reserves or Nature Parks such as the Central Catchment Nature Reserve, as well as the island of Pulau Ubin (Fig. 1).

Taking a closer look at the surrounding geography, Hampstead Wetlands Park is positioned within 2 kilometres of Seletar Mangroves, Seletar Wet Gap, Sungei Punggol Mangroves, and Yio Chu Kang Woods. The first three are wetlands while the fourth is a secondary forest. Together with these naturally vegetated sites, Hampstead Wetlands Park serves as an ecological "stepping stone" between biodiversity source sites such as Central Catchment Nature Reserve and Pulau Ubin. The ecological connectivity between these "stepping stones" is further enhanced and complemented by Nature Ways, Seletar West Park Connector, and other natural areas. Together, they form the Seletar Nature Corridor, which is an ecological corridor between Central Catchment Nature Reserve and Pulau Ubin.

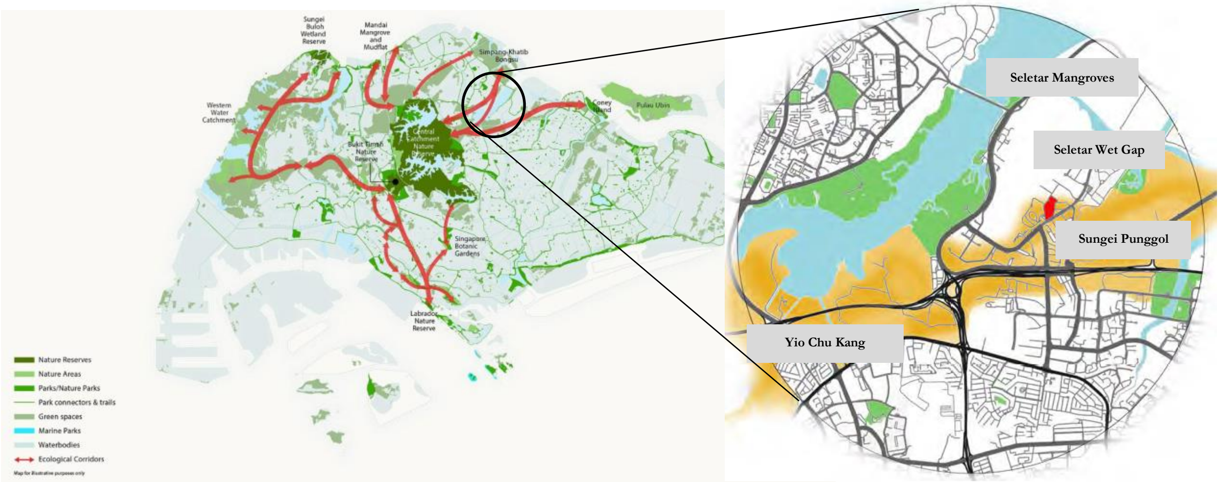


Fig. 1. A map showing possible pathways of ecological connection in Singapore, taken from an Ecological Profiling Exercise conducted as part of the Long Term Planning Review exhibition in 2022. The inset highlights the location of Hampstead Wetlands Park (red) in relation to the nearby rich biodiversity areas and Seletar Nature Corridor.

Habitat restoration during development

After a deeper understanding of the geography was obtained, the existing landscape prior to development was studied closely (Fig. 2). The pre-development landscape at Hampstead Wetlands Park could be broadly categorised into the forest core, the freshwater pond, and perimeter vegetation consisting of turf area and sparse trees.

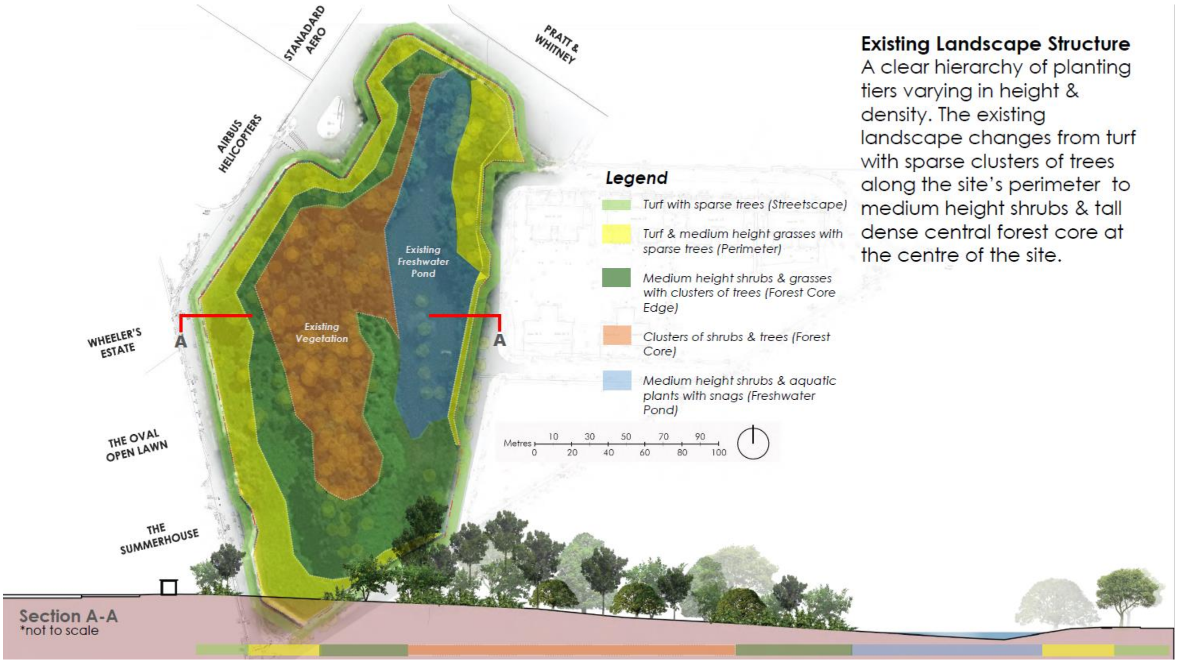
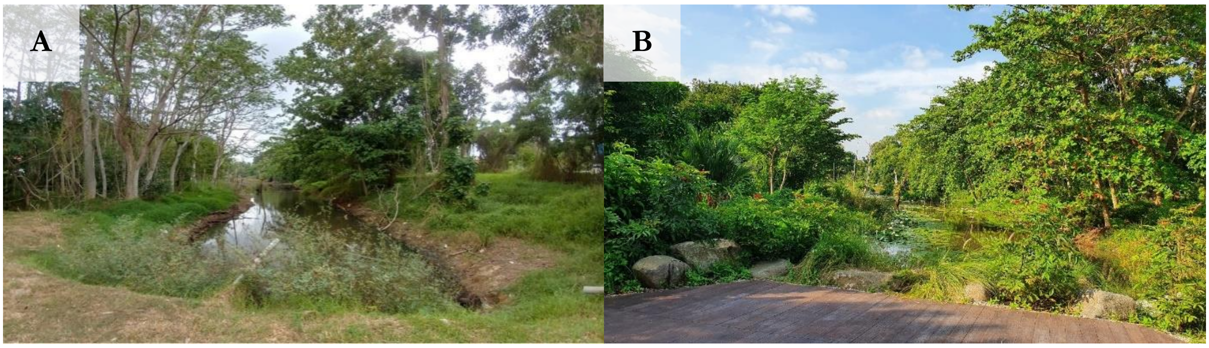


Fig. 2. Characterisation of the existing landscape at Hampstead Wetlands Park prior to development.

The forest core



Figs. 3. (A) Before development – Invasive dominated young secondary forest. The left side was dominated by Albizia trees; (B) After development – A diversity of freshwater swamp forest and tropical forest species were added into Hampstead Wetlands Park.

Prior to development, the young secondary forest which surrounded the wetlands comprised largely pioneer species and invasive species such as African Tulip (*Spathodea campanulata*), Albizia (*Falcataria moluccana*), and Leucaena (*Leucaena leucocephala*) (Fig. 3A). These tree species were known to have rapid growth in open sites which in turn dominated the landscape and could prevent the recovery of native forest on open sites (Nghiem *et al.*, 2015). These undesirable tree species were removed, and the forest was restored with largely native species to emulate the rainforest layers (Table 1).

Table 1. A list of tree and palm species planted at Hampstead Wetlands Park

Emergent	Canopy	Understory
Alstonia angustiloba	*Alstonia spatulata*	*Ardisia elliptica*
Cyrtophyllum fragrans	*Aquilaria malaccensis*	*Barringtonia asiatica*
Horsfieldia irya	*Buchanania arborescens*	*Barringtonia racemosa*
Palaquium obovatum	*Cerbera manghas*	*Eurycoma longifolia*
Pometia pinnata	*Cordia subcordata*	*Gnetum gnemon*
Sterculia macrophylla	*Cratoxylum cochinchinense*	*Ploiarium elegens*
	Cratoxylum formosum	*Syzygium borneense*
	Diospyros lanceifolia	*Syzygium zeylanicum*
	Elaeocarpus mastersii	*Tristaniopsis whiteana*
	Parkia speciosa	*Cyrtostachys renda*
	Sterculia parviflora	*Licuala spinosa*
	Syzygium syzygioides	*Oncosperma tigillarium*

Freshwater swamp forest species that could tolerate waterlogged soil or some inundation, such as *Alstonia spatulata*, *Horsfieldia irya*, *Ploiarium elegens*, and *Cyrtostachys renda*, were planted along the wetland edges (Fig. 3B). The forest edges were also planted with buffer shrubs such as *Melastoma malabathricum* and *Leea indica* which are characteristic of young secondary forests.

Native species are well suited to the local condition and therefore require less maintenance as well. These trees and shrubs provided shade, focal points, and screening as well as expanded on the range of habitats for biodiversity. Taking into consideration the eventual height of the tree saplings as they matured, the planting emulated the tiered structure of a forest, i.e., turf with sparse clusters of trees to medium height shrubs planted in the perimeter, and a tall, dense forest structure was deliberately created at the core.

Other than being part of a forest structure, the planted trees and shrubs could also support more biodiversity in the park. Fruit-bearing tree species were planted to diversify food options, such as *Ardisia elliptica*, *Syzygium zeylanicum*, and *Buchanania arborescens*. These attracted frugivorous birds such as the Yellow-vented Bulbul (*Pycnonotus goiavier*), Asian Glossy Starling (*Aplonis panayensis*), and Pink-necked Green Pigeon (*Treron vernans*). The flowering plants attracted many insect pollinators, which in turn attracted insectivorous animals such the Blue-tailed Bee-eater and Changeable Lizard (*Calotes versicolor*), that were then preyed upon by raptors.

The wetlands

Figs. 4. (A) Taken in March 2018 before development – the water body was badly polluted with rubbish; (B) Post development – an enhanced and diversified habitat for biodiversity.

Prior to development, the freshwater pond was badly polluted with rubbish, and the water body was almost devoid of aquatic plants (Fig. 4A). Macrophytes (aquatic plants that grow in or near water, and can be categorised as emergent, submergent, or floating) were planted within the water body, and water tolerant shrubs were planted at the margins of the water.

With the wetland habitat enhanced with a diversity of plants, microhabitats were created to accommodate biodiversity of different niche requirements (Fig. 4B). For example, different species of dragonfly nymph needed different microhabitats within a waterbody. Some burrowed into the pond sediment or leaf litter while some hid amidst the roots of the macrophytes (Ngiam, 2011). As the nymphs emerged from the water to transform into adult dragonflies, some would seek vertical support such as twigs or emergent plants (i.e., *Lepironia articulata*) to assist in its emergence. The reedbeds of sedges and shrubs also acted as hides for the water birds such as the White-breasted Waterhen (*Amaurornis phoenicurus*) and Slaty-breasted Rail (*Gallirallus striatus*) while cavity nesting birds such as woodpeckers, barbets, and parakeets made their nests in the snags within the wetlands. The constructed habitat mounds also served as a place of rest for biodiversity such as monitor lizards or Smooth-coated Otters (*Lutrogale perspicillata*).

The submerged parts of the plants also provided a surface for the attachment and growth of microbial biofilms, which were important for microbial processes that took up nutrients from the system such as nitrogen reduction (Yeo *et al.*, 2010). Wetlands help to remove sediments from surface run-off when it rained, acting as a natural filter before the water was drained into stormwater drains.

Perimeter vegetation

Fig. 5. Post development, a nature trail flanked with native shrub species.

Previously, the open sites were dominated by Lalang (*Imperata cylindrica*) that grew aggressively. During development, the invasive Lalang were removed and a Nature Trail flanked with native shrubs on both sides was created (Fig. 5). Passive rewilding was trialled at the edges of the forest, where the area was left to naturally recruit and form a buffer.

A butterfly garden with informal pathways had also been added to the park to provide habitat for biodiversity (Fig. 6). Butterfly-attracting nectar shrubs such as Common Lantana (*Lantana camara*) were planted, as well as host plants such as Candle Bush (*Senna alata*), Stinking Passionflower (*Passiflora foetida*), and Rukam Masam (*Flacourtia inermis*).

Figs. 6. A butterfly habitat with informal pathways and habitat log structures.

Enhancing the park user's experience

Besides habitat restoration, the park was also designed to allow users of the park to appreciate the landscape. The existing access and circulation of pedestrians were studied, as well as the sun path throughout the year.

The pre-development site was surrounded by covered linkways and concrete footpaths (Fig. 7). Workers from the surrounding offices and industrial areas used these footpaths as thoroughfares to the bus stop.

Fig. 7. The existing access and pedestrian's pathway around the pre-development land parcel.

After the site improvement, the wetlands buffered the noise and air pollution produced by the surrounding buildings and roads.

Careful design interventions using landscape layers enhanced the park user's experience. In creating these landscape layers, the design tapped on existing views of the forest core and wetland (Fig. 8). Strategically aligned around the forest core and wetland, the access routes comprising elevated boardwalks, nature trails, viewing decks, and informal paths, brought park users closer to nature while ensuring minimal disturbances to the habitats. Snags, tall reeds, and habitat mounds within the wetlands provided areas for organisms such as birds and dragonflies to perch on and escape from predators, while being easily observed by park users at a safe distance. Viewing decks were strategically located to draw the user's attention towards a view that gave a sense of continuity and depth (Fig. 9).

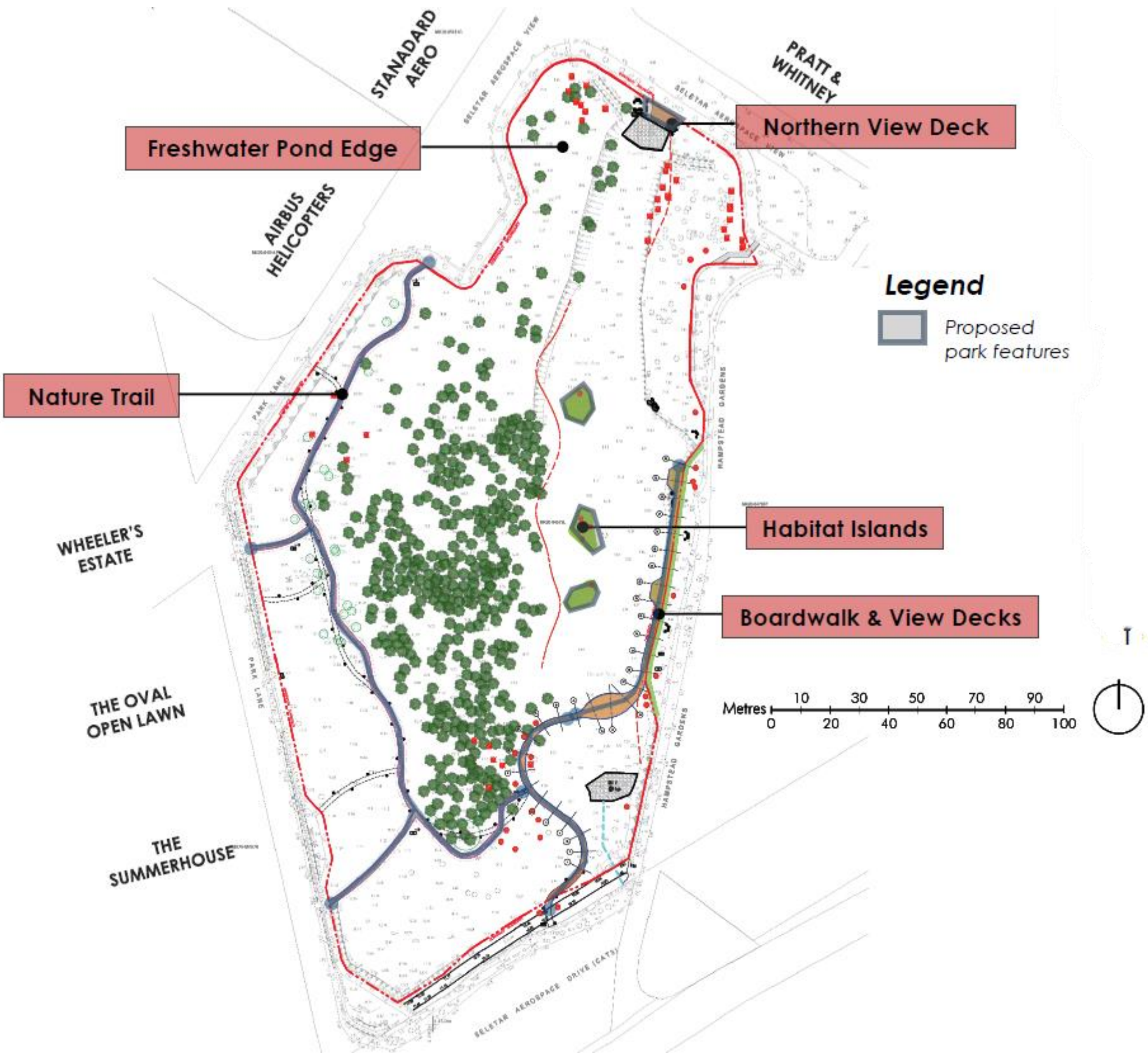


Fig. 8. Post development – Boardwalks, nature trail, habitat island, and view decks were added.

Fig. 9. Scene from the viewing decks that had been strategically located to guide park users' attention towards the wetlands and forest core.

As the design of the boardwalk takes into consideration the east-west orientation of the sun's direction, park users on the boardwalk are able to enjoy the shade from the spreading canopy of the Rain Trees (*Samanea saman*) along the road, while the morning sun casts light on the snags and forest core, providing photography opportunities for wildlife enthusiasts.

Materials and colours used for the park were selected to blend seamlessly with the natural surroundings. Soft edge planting helped to merge the built forms with the natural environment and encourage direct exploration of these natural habitats at close proximity. Educational elements such as interpretive signage found throughout the park enriched the park user experience by highlighting some of the rich biodiversity that can be found there.

Biodiversity

A brief survey was carried out prior to development in 2019. Only a handful of species was recorded: Blue-tailed Bee-eater, Blue-throated Bee-eater (*Merops viridis*), White-throated Kingfisher, Oriental Pied Hornbill, Blue Percher (*Diplacodes trivialis*), Common Parasol (*Neurothemis fluctuans*), and Common Grass Yellow (*Eurema hecabe contubernalis*).

Since its opening in April 2020, at least 120 species of birds (28.4% of the total number of bird species in Singapore) (Table 2), 33 species of butterflies (9.9% of the total number of butterfly species in Singapore) (Table 3), and 14 species of dragonflies and damselflies (10.3% of the total number of odonate species in Singapore) (Table 4) had been observed in the park. Inferring from the comparative figures above, Hampstead Wetlands Park appears to be supporting more bird, butterfly and odonate species than expected based on its physical size. Its location and enhanced habitats must have contributed significantly to these records.

Table 2: Bird species recorded at Hampstead Wetlands Park (Source: eBird)

	Common name	Scientific name
1	Lesser Whistling-Duck	*Dendrocygna javanica*
2	Cotton Pygmy-Goose	*Nettapus coromandelianus*
3	Mallard	*Anas platyrhynchos*
4	Red Junglefowl	*Gallus gallus*
5	Rock Pigeon	*Columba livia*
6	Spotted Dove	*Spilopelia chinensis*
7	Zebra Dove	*Geopelia striata*
8	Pink-necked Green-Pigeon	*Treron vernans*
9	Thick-billed Green-Pigeon	*Treron curvirostra*
10	Pied Imperial-Pigeon	*Ducula bicolor*
11	Lesser Coucal	*Centropus bengalensis*
12	Chestnut-winged Cuckoo	*Clamator coromandus*
13	Asian Koel	*Eudynamys scolopaceus*
14	Little Bronze-Cuckoo	*Chrysococcyx minutillus*
15	Banded Bay Cuckoo	*Cacomantis sonneratii*
16	Plaintive Cuckoo	*Cacomantis merulinus*
17	Brush Cuckoo	*Cacomantis variolosus*
18	Square-tailed Drongo-Cuckoo	*Surniculus lugubris*
19	Hodgson's Hawk-Cuckoo	*Hierococcyx nisicolor*
20	Gray Nightjar	*Caprimulgus jotaka*
21	Large-tailed Nightjar	*Caprimulgus macrurus*
22	Plume-toed Swiftlet	*Collocalia affinis*
23	Pacific Swift	*Apus pacificus*
24	Asian Palm Swift	*Cypsiurus balasiensis*

Table 2: Bird species recorded at Hampstead Wetlands Park (Source: eBird) *(Cont'd)*

	Common name	Scientific name
25	Slaty-breasted Rail	*Lewinia striata*
26	White-breasted Waterhen	*Amaurornis phoenicurus*
27	Common Sandpiper	*Actitis hypoleucos*
28	Asian Openbill	*Anastomus oscitans*
29	Yellow Bittern	*Ixobrychus sinensis*
30	Cinnamon Bittern	*Ixobrychus cinnamomeus*
31	Black Bittern	*Ixobrychus flavicollis*
32	Gray Heron	*Ardea cinera*
33	Purple Heron	*Ardea purpurea*
34	Great Egret	*Ardea alba*
35	Intermediate Egret	*Ardea intermedia*
36	Little Egret	*Egretta garzetta*
37	Cattle Egret	*Bubulcus ibis*
38	Striated Heron	*Butorides striata*
39	Osprey	*Pandion haliaetus*
40	Black-winged Kite	*Elanus caeruleus*
41	Oriental Honey-buzzard	*Pernis ptilorhynchus*
42	Changeable Hawk-Eagle	*Nisaetus cirrhatus*
43	Crested Goshawk	*Accipiter trivirgatus*
44	Japanese Sparrowhawk	*Accipiter gularis*
45	Brahminy Kite	*Haliastur indus*
46	White-bellied Sea-Eagle	*Haliaeetus leucogaster*
47	Gray-headed Fish-Eagle	*Haliaeetus ichthyaetus*
48	Buffy Fish-Owl	*Ketupa ketupu*
49	Spotted Wood-Owl	*Strix seloputo*
50	Oriental Pied-Hornbill	*Anthracoceros albirostris*
51	Common Kingfisher	*Alcedo atthis*
52	Black-backed Dwarf-Kingfisher	*Ceyx erithaca*
53	Stork-billed Kingfisher	*Pelargopsis capensis*

Table 2: Bird species recorded at Hampstead Wetlands Park (Source: eBird) *(Cont'd)*

	Common name	Scientific name
54	White-throated Kingfisher	*Halcyon smyrnensis*
55	Collared Kingfisher	*Todiramphus chloris*
56	Blue-throated Bee-eater	*Merops viridis*
57	Blue-tailed Bee-eater	*Merops philippinus*
58	Dollarbird	*Eurystomus orientalis*
59	Coppersmith Barbet	*Psilopogon haemacephalus*
60	Lineated Barbet	*Psilopogon lineatus*
61	Sunda Pygmy Woodpecker	*Yungicus moluccensis*
62	Rufous Woodpecker	*Micropternus brachyurus*
63	Common Flameback	*Dinopium javanense*
64	Laced Woodpecker	*Picus vittatus*
65	Banded Woodpecker	*Chrysophlegma miniaceum*
66	Peregrine Falcon	*Falco peregrinus*
67	Rose-ringed Parakeet	*Psittacula krameri*
68	Red-breasted Parakeet	*Psittacula alexandri*
69	Long-tailed Parakeet	*Psittacula longicauda*
70	Blue-crowned Hanging-Parrot	*Loriculus galgulus*
71	Blue-winged Pitta	*Pitta moluccensis*
72	Golden-bellied Gerygone	*Gerygone sulphurea*
73	Ashy Minivet	*Pericrocotus divaricatus*
74	Pied Triller	*Lalage nigra*
75	Black-naped Oriole	*Oriolus chinensis*
76	Common Iora	*Aegithina tiphia*
77	Malaysian Pied-Fantail	*Rhipidura javanica*
78	Amur Paradise-Flycatcher	*Terpsiphone incei*
79	Brown Shrike	*Lanius cristatus*
80	Long-tailed Shrike	*Lanius schach*
81	House Crow	*Corvus splendens*
82	Large-billed Crow	*Corvus macrorhynchos*

Table 2: Bird species recorded at Hampstead Wetlands Park (Source: eBird) *(Cont'd)*

	Common name	Scientific name
83	Common Tailorbird	*Orthotomus sutorius*
84	Dark-necked Tailorbird	*Orthotomus atrogularis*
85	Ashy Tailorbird	*Orthotomus ruficeps*
86	Rufous-tailed Tailorbird	*Orthotomus sericeua*
87	Yellow-bellied Prinia	*Prinia flaviventris*
88	Zitting Cisticola	*Cisticola juncidis*
89	Oriental Reed Warbler	*Acrocephalus orientalis*
90	Barn Swallow	*Hirundo rustica*
91	Pacific Swallow	*Hirundo tahitica*
92	Red-whiskered Bulbul	*Pycnontus jocosus*
93	Sooty-headed Bulbul	*Pycnonotus aurigaster*
94	Yellow-vented Bulbul	*Pycnonotus goiavier*
95	Yellow-browed Warbler	*Phylloscopus inornatus*
96	Arctic Warbler	*Phylloscopus borealis*
97	Swinhoe's White-eye	*Zosterops simplex*
98	Pin-striped Tit-Babbler	*Mixornis gularis*
99	White-crested Laughingthrush	*Garrulax leucolophus*
100	Asian Glossy Starling	*Aplonis panayensis*
101	Daurian Starling	*Agropsar sturninus*
102	White-shouldered Starling	*Sturnia sinensis*
103	Common Myna	*Acridotheres tristis*
104	Javan Myna	*Acridotheres javanicus*
105	Dark-sided Flycatcher	*Muscicapa sibirica*
106	Asian Brown Flycatcher	*Muscicapa dauurica*
107	Brown-steaked Flycatcher	*Muscicapa williamsoni*
108	Oriental Magpie-Robin	*Copsychus saularis*
109	Yellow-rumped Flycatcher	*Ficedula zanthopygia*
110	Orange-bellied Flowerpecker	*Dicaeum trigonostigma*
111	Scarlet-backed Flowerpecker	*Dicaeum cruentatum*

Table 2: Bird species recorded at Hampstead Wetlands Park (Source: eBird) *(Cont'd)*

	Common name	Scientific name
112	Brown-throated Sunbird	*Anthreptes malacensis*
113	Olive-backed Sunbird	*Cinnyris jugularis*
114	Asian Golden Weaver	*Ploceus hypoxanthus*
115	Scaly-breasted Munia	*Lonchura punctulata*
116	Javan Munia	*Lonchura leucogastroides*
117	Chestnut Munia	*Lonchura atricapilla*
118	White-headed Munia	*Lonchura maja*
119	Eurasian Tree Sparrow	*Passer montanus*
120	Paddyfield Pipit	*Anthus rufulus*

Table 3: Butterfly species recorded at Hampstead Wetlands Park

	Common name	Scientific name
1	Bengal Swift	*Pelopidas agna agna*
2	Blue Pansy	*Junonia orithya wallacei*
3	Chestnut Bob	*Iambrix salsala salsala*
4	Chocolate Pansy	*Junonia hedonia ida*
5	Ciliate Blue	*Anthene emolus goberus*
6	Common Bluebottle	*Graphium sarpedon luctatius*
7	Common Grass Yellow	*Eurema hecabe contubernalis*
8	Common Mime	*Chilasa clytia clytia*
9	Common Mormon	*Papilio polytes romulus*
10	Common Palm Dart	*Telicota colon stinga*
11	Common Palmfly	*Elymnias hypermnestra agina*
12	Common Tit	*Hypolycaena erylus teatus*
13	Contiguous Swift	*Polytremis lubricans lubricans*
14	Copper Flash	*Rapala pheretima sequeira*
15	Dingy Bush Brown	*Mycalesis perseus cepheus*
16	Formosan Swift	*Borbo cinnara*
17	Ganda Dart	*Potanthus ganda ganda*

Table 3: Butterfly species recorded at Hampstead Wetlands Park *(Cont'd)*

	Common name	Scientific name
18	Julia Heliconian	*Dryas iulia*
19	King Crow	*Euploea phaenareta castelnaui*
20	Lemon Emigrant	*Catopsilia pomona pomona*
21	Lesser Dart	*Potanthus omaha omaha*
22	Lesser Grass Blue	*Zizina otis lampa*
23	Lime Butterfly	*Papilio demoleus malayanus*
24	Long Brand Bush Brown	*Mycalesis visala phamis*
25	Mottled Emigrant	*Catopsilia pyranthe pyranthe*
26	Painted Jezebel	*Delias hyparete metarete*
27	Peacock Pansy	*Junonia almana javana*
28	Pygmy Grass Blue	*Zizula hylax pygmaea*
29	Short Banded Sailor	*Phaedyma columella singa*
30	Small Branded Swift	*Pelopidas mathias mathias*
31	Striped Albatross	*Appias libythea olferna*
32	Tawny Coster	*Acraea terpsicore*
33	White-tipped Skipper	*Erionota hiraca apicalis*

Table 4: Dragonfly and damselfly species recorded at Hampstead Wetlands Park

	Common name	Scientific name
1	Blue Dasher	*Brachydiplax chalybea*
2	Blue Sprite	*Pseudagrion microcephalum*
3	Common Bluetail	*Ischnura senegalensis*
4	Common Parasol	*Neurothemis fluctuans*
5	Common Scarlet	*Crocothemis servilia*
6	Dancing Dropwing	*Trithemis pallidinervis*
7	Emperor	*Anax guttatus*
8	Ornate Coraltail	*Ceriagrion cerinorubellum*
9	Scarlet Pygmy	*Nannophya pygmaea*
10	Scarlet Skimmer	*Crocothemis servilia*

Table 4: Dragonfly and damselfly species recorded at Hampstead Wetlands Park *(Cont'd)*

11	Spine-Tufted Skimmer	*Orthetrum chrysis*
12	Variegated Green Skimmer	*Orthetrum sabina*
13	Wandering Glider	*Pantala flavescens*
14	Yellow-barred Flutterer	*Rhyothemis phyllis*

Relationship between people and the park

Just steps away from the road and bus stop, Hampstead Wetlands Park is easily accessible, which meant that it could be easily exposed to negative anthropogenic issues. Illegal release or accidental contamination could result in the presence of Red-eared Slider (*Trachemys scripta elegans*), Arowana (*Scleropages* sp.), Motoro Stingray (*Potamotrygon* sp.), Golden Apple Snails (*Pomacea canaliculata*), *Hydrilla*, and poultry such as Chukar Partridge (*Alectoris chukar*) and Cayuga Ducks (*Anas platyrhynchos domesticus*) being found in the park. While some of the alien species were easily removed or relocated, some species reproduced rapidly and dominated the habitat, such as the *Hydrilla*, and active maintenance was required to rebalance the habitat. The habitats at Hampstead Wetlands Park had been vastly improved by the inclusion of native species to emulate a rainforest or a freshwater swamp.

Although Hampstead Wetlands Park occupies only 3.23 hectares, nevertheless, the ecological, recreational, and social benefits contributed by this small site far outweigh its physical size when we take on a bigger picture perspective. Hampstead Wetlands Park serves as an accessible educational platform, where the public can have a positive encounter with biodiversity and learn about the native biodiversity and habitats which they would otherwise not have been able to experience in a usual urban setting.

The appeal of Hampstead Wetlands Park cuts across all ages, as attested by the sharing of the experiences of four stalwarts. Mr Lau Foon Wah, 65, is a regular visitor to the Seletar area as part of his daily morning routine. He observed that he was able to encounter more biodiversity in the park after the habitat restoration and development works in the park and had picked up photography to document the biodiversity in the park. Mr Lau commented that it was easy to observe wildlife from the boardwalk and recounted that one of his fondest experiences at the park was witnessing a family of Common Flamebacks – from the mating pair forming a nest together to when the fledgings left the nest.

Figs. 10. A pair of Common Flamebacks taking turns to excavate a cavity nest in a snag located within the wetlands. The male has a crimson marking while the female has duller markings. (Photo credit: Lau Foon Wah)

Mr Siew Weng Chee, 66, is another regular visitor at Hampstead Wetlands Park. He commented that his visits and encounters with biodiversity energised and improved his well-being. He added that the interaction with the nature-watching community in the park was equally important in improving his well-being as well as adding to his knowledge of biodiversity.

Ms Joey Gao, 23, first heard of Hampstead Wetlands Parks when she saw photographs of a family of Buffy Fish Owls. Interest piqued, she visited the park multiple times and was fascinated to witness the growth of the Buffy Fish Owl juvenile, its attempts to leave its nest, hunt, and interactions with other bird species. Mr Wayne Chng (26 years old) enjoyed visiting the park as it was easily accessible and recounted his experience in the rain where he was able to observe the wildlife reacting to the rain. He was amazed to see Smooth-coated Otters diving into the ponds, Buffy Fish Owls, and Blue-tailed Bee Eaters finding spots to perch to escape the rain.

Habitat restoration and enhancement works has resulted in a notable increase in biodiversity in Hampstead Wetlands Park. Consequently, the ecosystem services' benefits that arose were manifold, including physical, mental, and psychological well-being. There are multiple hypotheses on the restorative benefits of people immersing themselves in nature, including casual observation of biodiversity such as birdwatching. According to the Attention Restoration Theory, a person spending time in nature uses involuntary or effortless attention on his surroundings, and this could improve his concentration and relieve mental fatigue. Several park users expressed the positive psychological effects that they experienced due to the increase in biodiversity. With the popularity of social media platforms, many park users were able to share their positive biodiversity encounters.

Conclusion

As Singapore continues to urbanise, it is important to ensure that Singapore remains a highly liveable city. NParks' vision of creating a City in Nature is a part of the Singapore 2030 Green Plan that is a whole-of-nation movement to advance Singapore's national agenda on sustainable development. Restoring nature into the urban landscape, as exemplified by the development of Hampstead Wetlands Park within the Seletar industrial zone, is one of the key strategies to achieve this vision.

While Hampstead Wetlands Park is a mere 3.23 hectares, the continuing efforts to enhance the habitat at a small scale by deliberately planning to improve ecological connectivity showed that large improvements to biodiversity and positive park user experience could be achieved despite other limitations and challenges. Beyond the tangible presence of the park, the shared experiences of a community planting trees together to enhance the habitat, as well as the casual sharing of biodiversity knowledge between park users or through social media, played a multiplier effect in enriching liveability and social cohesion in Singapore.

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CHAPTER 20

Mangrove Restoration in Pulau Ubin

Robert Teo

Introduction

An early topographical map produced by the British colonial government in 1939 showed that Pulau Ubin used to be a cluster of five land masses separated by tidal mangrove rivers (Fig. 1) and mangrove and associated intertidal swamp constituted about 40% of the vegetation cover. Much of the original mangrove vegetation was cleared with the introduction of prawn farming and the five disparate land bodies were eventually connected into the single island of today through the infilling of intertidal areas and the building of bunds and bridges. By the 1960s, about 50% of the original mangrove and intertidal swamp habitats had already been converted to prawn farms or land.

Fig. 1. Topographical map of Pulau Ubin, 1939. (Image credit: Maps MOD GSGS 3772 Sheet 3 L/12b Second Edition, The British Library)

From the 1990s, the economic viability of prawn farming declined and mangroves started to regenerate naturally at the abandoned prawn farm sites. The National Parks Board (NParks) began actively restoring mangroves from 2005, and mangroves and intertidal swamps now make up about 25% of the current vegetation cover on Pulau Ubin.

This paper looks at one mangrove restoration project on Pulau Ubin.

Mangrove restoration at Chek Jawa Wetlands

The project at Chek Jawa Wetlands centred on an abandoned prawn farming pond covering about 2 hectares, within a 6-hectare mangrove forest area (Fig. 2). Based on aerial photographs from the Ministry of Defence, the pond was in operation from at least 1969 to 1999. The prawn farming utilised local traditional farming methods, comprising a pond surrounded by mud bunds, with a sluice gate to control tidal inundation. The bunds were likely formed from mud excavated to create the pond and consisted of fine clay with remnants of mangrove mollusc shells.

With the cessation of prawn farming operations, mangroves started to colonise naturally in shallower areas of the pond by 2001 (Fig. 3). A project to expedite the natural colonisation of mangroves commenced in 2005. Alien invasive plant species (e.g., *Acacia auriculiformis* and *Falcataria falcata*) which had established around the abandoned pond were removed, and the bunds were levelled down (Fig. 4 & 5) to allow inundation during high tides and exposure as the tides recede. The excavated materials were used to fill in the sides of the pond to raise the bottom of the pond in those areas. The restoration efforts facilitated the natural dispersal and establishment of mangrove seedlings in the relevelled areas – along the former bunds and the sides of the pond.

Fig. 2. Aerial photograph showing mangrove area at Chek Jawa Wetlands in 2001.

Fig. 3. Aerial photograph showing close-up of abandoned pond in 2001.

Fig. 4. Bunds around the pond were levelled down. Part of the bund yet to be cleared then can be seen on the right.

Fig. 5. The relevelled bunds facilitated natural mangrove colonisation.

By 2017, mangrove vegetation had covered about 90% of the subject site (Fig. 6). Only the deepest areas of the pond where the elevations are lowest were not colonised by mangrove vegetation. Species that colonised the relevelled areas included *Acrostichum speciosum, Avicennia alba, A. officinalis, A. rumphiana, Brugueira cylindrica, B. gymnorhiza, Ceriops zipelliana, Excoecaria agallocha, Heritiera littoralis, Nypa fruitcans, Rhizophora apiculata, R. mucronata, Sonneratia alba, S. ovata, Scyphiphora hydrophyllacea, Hibiscus tiliaceus, Thespesia polpunea, Xylocarpus granatum,* and *X. moluccensis*.

Fig. 6. Mangrove coverage of pond. (Image credit: Google Earth, 2017)

Conclusion

The success of the project highlighted the effectiveness of modifying site conditions through removing alien species, modifying substrate levels, and ensuring inundation that facilitated the natural regeneration of mangroves, without the need to plant mangrove saplings. Lessons learnt from the project and a research collaboration with the Geography Department of the National University of Singapore from 2016–2017 are being applied to other mangrove restoration efforts on Pulau Ubin.

CHAPTER 21

Conservation and Restoration of Pasir Ris Park Mangroves

Mohamad Yusoff

Introduction

In 1820, mangrove swamps covered about 13% of Singapore's fringe coastal areas (Ng & Sivasothi, 1999). By 2010, these ecosystems occupied less than 0.5% of Singapore's total land area. The existing mangroves are mostly concentrated in the northern and northeastern coast of Singapore, as well as offshore islands. Mangroves in Singapore is under pressure for more than 200 years due to development and rapid urbanisation. It is crucial to intensify efforts to conserve the remaining mangroves and restore the mangrove ecosystem as they protect the coastal areas, ameliorate effects of rising sea-levels, serve as homes to native flora and fauna, and provide numerous essential ecosystem services.

Objectives

This chapter documents the conservation and restoration works conducted at Pasir Ris Park which is the first urban park to feature the restoration of the natural mangrove ecosystem, through:

1) Improving the hydrology by bringing brackish water to the middle and back of mangrove zone,
2) Creating a mangrove nursery by propagating local stocks, and
3) Removing invasive terrestrial plants and replacing them with mangrove species using local stocks.

Materials and methods

Improve the hydrology

During land reclamation at Pasir Ris between 1978 and 1979, a 5-hectare patch of mangroves was carefully conserved by maintaining the tidal inundation. Over the years, it was observed that the middle and back mangrove received less brackish water from the sea and more freshwater from the overland flow from adjacent park land. These factors caused the soil salinity at the middle and back mangrove to decrease. A large area was occupied by hardy terrestrial plants.

It was essential to modify the hydrology of the mangrove by increasing the flow of seawater to the middle and back mangrove before the introduction of more mangrove species to the area. To improve the hydrology, tidal influence and substrate profile had to be studied.

Tidal influence

The analysis of these factors was largely based on visual survey and research materials. Studies were carried out over several days to record the correlation between different tidal height levels and inundation levels. It was observed that the back mangrove would only be inundated when the tides were 2.9 metres or higher. As a tide level of this height did not occur regularly, the back mangrove was often left drier. The source of water for the back mangrove came from the overland flow from abutting park land. As such, hardy freshwater plants species such as *Andira inermis*, *Acacia auriculiformis*, *Syzygium grande*, *Hibiscus tiliaceum*, *Cerbera odollam*, *Terminalia catappa*, *Pittosporum tobira*, and other creepers were observed to be taking over these spaces.

Substrate profile

Substrate profile was categorised according to sediment size and colour of the soil. Light coloured porous soil profile with bigger sediments was categorised as sandy, while dark coloured soil profile with finer silky sediments was categorised as muddy. The sandy soil was suspected to have been washed down from upstream, causing the downstream ground level to be raised over the years. This impeded the flow of brackish water to the back mangrove area. It was also observed that the trenches or rivulets that were created many years ago were now covered and filled with thick silt, which obstructed the flow of brackish water to the back mangrove.

To improve the hydrology at the back mangrove, soil was unearthed at several sites to investigate the feasibility of creating new trench lines to bring in water from the river to the back mangrove. The extent of tidal influence for each site was studied through observing the water trail marks on bakau (*Rhizophora* species) poles that were installed on the ground. Water trail marks on the bakau poles indicated the presence of heavy downpour or high tide. Once suitable sites for the new trenches were identified, 15 to 20 pieces of 1.5-metre-long bakau poles were used to mark out the new trench lines at each site (Fig. 1–3). Excavation was carried out to create new trench lines along the pole peg line from the river to the back mangrove. For the existing trench lines and rivulets, desilting was carried out to deepen the trenches and allow higher volume of brackish water to reach the drier area of the back mangrove.

The locations of the existing and newly created trench lines were recorded using GPS. These GPS points were transferred onto Google Earth for a comprehensive overview of the network of trench lines within the mangrove (Fig. 4). GPS plotting of the trench lines was essential in the study and management of the brackish water inundation within the mangrove. This would help to project the manpower requirements and funds needed for the desilting work on a year-to-year basis.

Fig. 1. Preparing for the surveying and marking of new trench lines with bakau poles at suitable sites.

Fig. 2. Surveying and marking new trench lines at suitable sites.

Fig. 3. Checking the new trench lines at suitable sites.

Fig. 4. Map of trench lines using GPS. (Image credit: Google Earth)

Other than creating trenches to bring in brackish water, regrading of the profile covering over 2,584 square metres was also carried out to ensure natural inundation of brackish water.

Creation of a mangrove nursery to propagate local stocks

During the site survey, it was observed that there were mangrove saplings overcrowding below the parent plants. Some of these plants would not be able to reach their potential growth as they would be deprived of full sunlight. These plants were also observed to be exhibiting signs of drying up such as turning brown and having dead terminal foliage.

The cluttered sites were marked and the overcrowded propagules and saplings below their mother plants were identified for salvaging (Fig. 5). The plants were salvaged for the replacement planting. A corer was used for the salvaging exercises as it was more efficient compared to doing manual trenching using a *cangkul* (i.e., a hoe) (Fig. 6). More than 1,000 mangrove saplings were salvaged from the exercises (Table 1). A mangrove nursery was created for the salvaged saplings to adapt and acclimatise before being reintroduced to the new planting site (Fig. 7–8). The site of the nursery location was carefully selected based on the natural soil profile where it was naturally inundated by sea water.

Fig. 5. Selective thinning was carried out on bigger *Bruguiera parviflora* saplings in a crowded site.

Fig. 6. Corer used to take out plants from the forest floor to mangrove nursery for acclimatisation.

Table 1. Breakdown of the species and number of saplings salvaged.

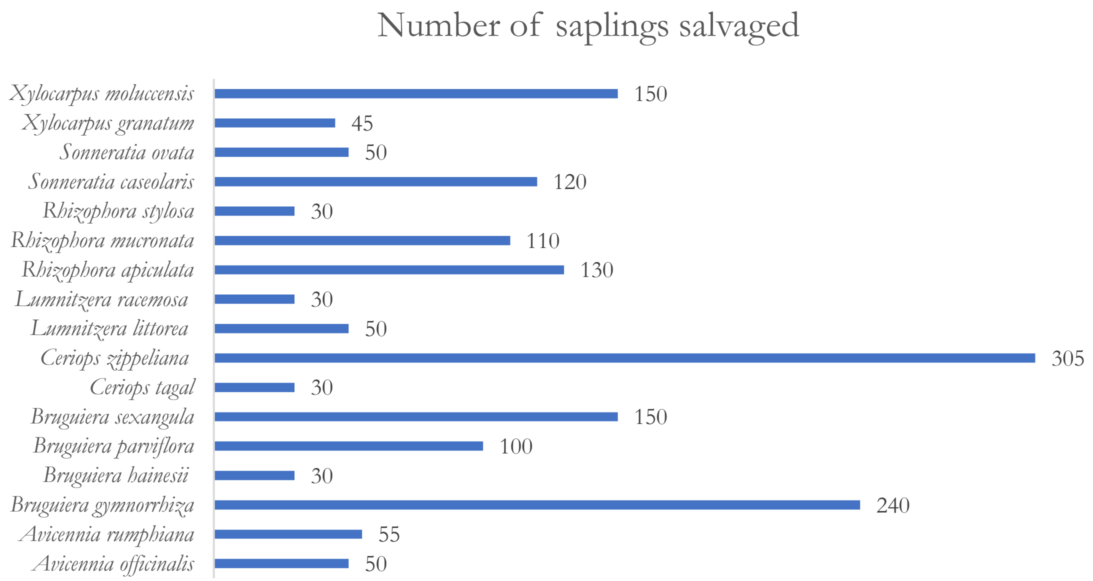

Fig. 7. Mangrove nursery in Pasir Ris Park.

Figs. 8. (A) Mangroves growing in plastic bags; (B) Mangroves planted on the ground before being transplanted back on site.

Removal of terrestrial plants and replacement with mangrove species

As terrestrial plants were observed to have taken over the back mangroves area, clearing of the existing vegetation was necessary to prevent competition with the slower growing mangroves plants. Over 400 square metres of terrestrial plants were removed (Fig. 10) and replaced with mangrove plant species that were salvaged (Fig. 11).

Fig. 10. Before the clearing of the terrestrial plants.

Fig. 11. Cleared area planted with salvaged and mangrove saplings grown in the nursery.

Results

After the new trenches were created, existing trenches were desilted, and the soil profile was regraded, it was observed that high volume of brackish water reached the drier area of the back mangrove (Fig. 12 & 13). This resulted in the creation of a favourable condition for mangrove species to colonise the area.

Fig. 12. Existing trench line before desilting.

Fig. 13. Existing trench line after desilting.

With the favourable mangrove site condition, saplings that were salvaged and nursed were reintroduced back to Pasir Ris Park mangrove following the clearance of terrestrial plants.

Monitoring of the growth and health of new plantings was carried out every fortnight. Observations revealed that the fatality of the new plants was very low and there was no visible negative impact to the surroundings. As the area was fairly bare after terrestrial plants were cleared, dried palms fronds from the park were used to cover the tree bases to reduce evaporation and transpiration. This operation helped speed up the growth of many mangrove tree species (Fig. 14).

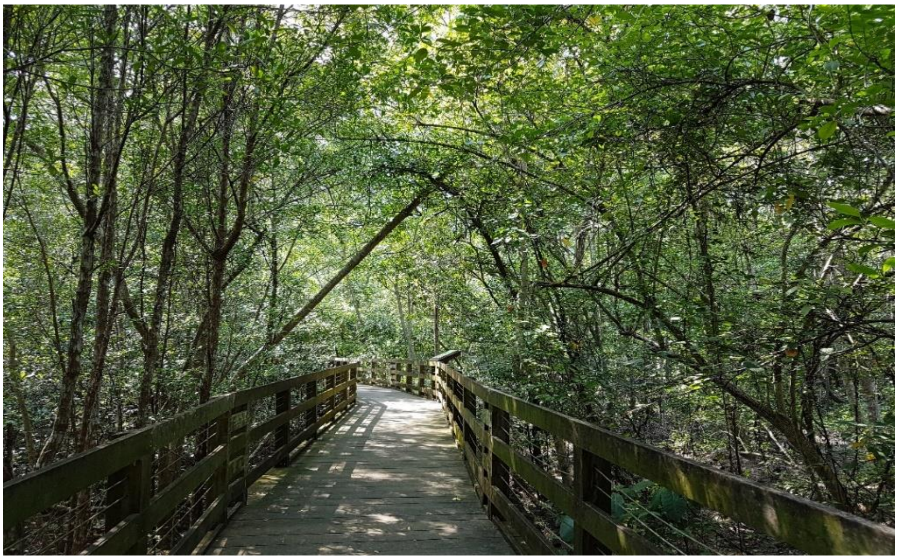

Fig. 14. Healthy thriving mangroves in Pasir Ris Park after restoration efforts.

Conclusion

Tidal reclamation and development disturbed the natural mangrove ecosystem at Pasir Ris, resulting in a change in soil profile, increase in terrestrial plants, and reduction of mangrove plants. With appropriate human intervention that improved the hydrology, removal of terrestrial species, and re-introduction of native back mangrove species, the health and integrity of the mangrove ecosystem were restored. This set of restorative method could serve as a model to be replicated at other parks that need to carry out mangrove enhancement planting under a similar environment and conditions.

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CHAPTER 22

Artificial Tidal Pools: Habitat Enhancement of Built-up Shorelines of Singapore

Nhung Nguyen Thi Hong, Karenne Tun, Tan Yit Chuan & Lena Chan

Introduction

Over the last eight decades, Singapore's coastal landscapes have gone through significant transformation. An island skirted by mangroves and mudflats, Singapore has become a modern-day coastal city state that is one of the most populated metropolises in the world. Seawalls, headlands, and breakwaters are built along the coast to protect valuable land and inland assets from coastal erosion and inundation. The majority of Singapore's contemporary coastline is thus reinforced by sea defences and other forms of coastal infrastructure.

Sea defences to shore up the coastlines are a fundamental need for small coastal city states like Singapore, especially in the context of land scarcity, expanding population and countering impacts from climate change. While sea defences and coastal infrastructure are largely permanent engineered structures, they are, however, not purpose-built for supporting biodiversity. One strategy is to enhance the capacity of these structures through purposeful engineered modifications to compensate for and replace lost biodiversity without compromising their intended functions. This requires a mindset change that challenges us to understand the functions of coastal infrastructure beyond engineering goals and to explore opportunities for supporting and restoring biodiversity. Ecologically informed engineering in the design and construction of coastal infrastructure can reduce the loss of intertidal and shallow water biodiversity on artificial shorelines.

The objectives of the project were to: (1) design and develop biophilic habitat enhancement structures for modified coastlines; and (2) create opportunities to engage researchers to study the establishment and succession of communities in the structures.

Methodology

Study of conditions contributing to natural recruitment of organisms on artificial structures

Seawalls support a relatively high diversity of intertidal organisms and share several metrics with rocky shores, such as the number of species present and dominant species. For example, the presence of hard substrates, such as granite armour rocks used for shoreline reinforcement, can support the recruitment of biodiverse corals and other reef organisms in areas where reefs either used to exist, or could exist if suitable substrate were present. We observed this phenomenon along seawalls at reclaimed sites such as Pulau Semakau, East Coast, and Marina East that continue to support rich assemblages of corals in less than a decade after the completion of reclamation works. Similar biodiversity revival within marinas were also seen in the submerged walls of the floating pontoons used for berthing boats that supported rich assemblages of marine organisms. In particular, the concrete coating used for the submerged walls provided suitable surfaces that encouraged the recruitment of marine organisms. However, the uniformity of seawall construction material, the inclination of their surfaces, and the lack of microhabitats such as holes, cracks, crevices and rock pools resulted in lower biodiversity assemblages compared to natural rocky shores.

Our observations of biodiversity occurring by chance along artificially engineered coastal structures presented us with the perfect opportunity for studying the factors that facilitated their successful development, such as surface material, rugosity, slope gradient and hydrodynamic regimes, among others. We adapted and then applied these factors to intentionally enhance the biodiversity of other existing and future coastal structures. Recent investigations suggested that larval supply of marine organisms was not limited in Singapore. However, the availability of suitable habitat is limited in many areas. We believe that by introducing appropriate substrates in the right environment, coupled with effective management of human activities, marine biodiversity can be revived or enhanced along otherwise barren areas. One way to do this is through the reverse engineering of structures – i.e., extracting design information from a manmade structure/object and using this information to enhance other structures/objects – to understand the design and engineering aspects and environmental factors that facilitated the recruitment of organisms in the examples described above. We looked at the nature of the built structure from the type of material used, the methods of construction, surface complexity, inclination, hydrodynamic conditions, exposure to varying tidal regimes and anthropogenic activities, and the historical condition of the sites that contributed to their ability to host and support biodiversity. Based on those metrics, we investigated different strategies for biodiversity enhancement and developed the following framework to assess coastal structures and their capacity to host biodiversity (Fig. 1).

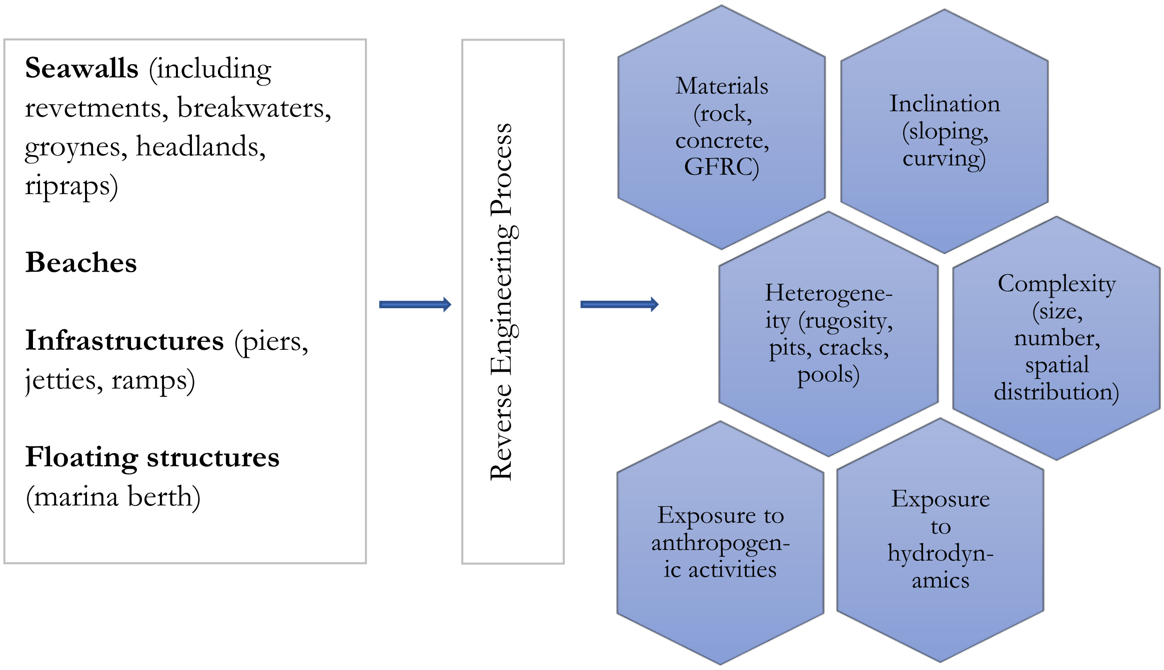


Fig. 1. A framework to assess coastal structures and their friendliness toward biodiversity.

Design and development of enhancement structure

We identified and investigated strategies for increasing the heterogeneity and complexity of built surfaces, introducing novel habitats such as tidal pools, enhancement units, and textured tiles, manipulating the substrate, planting coastal vegetation, and incorporating purpose-built elements to coastal structures.

We found that for enhancement on existing seawalls and coastal structures, surface complexity was the most important and also the most easily manipulated amongst all assessment criteria. Complexity could be manipulated at different spatial scales, ranging from millimetre to metre, and targeting different organismal behaviour. We worked with four complexity parameters that were developed in a separate research project by our research collaborators from the National University of Singapore, namely (1) the number of object types; (2) the relative abundance of object types;

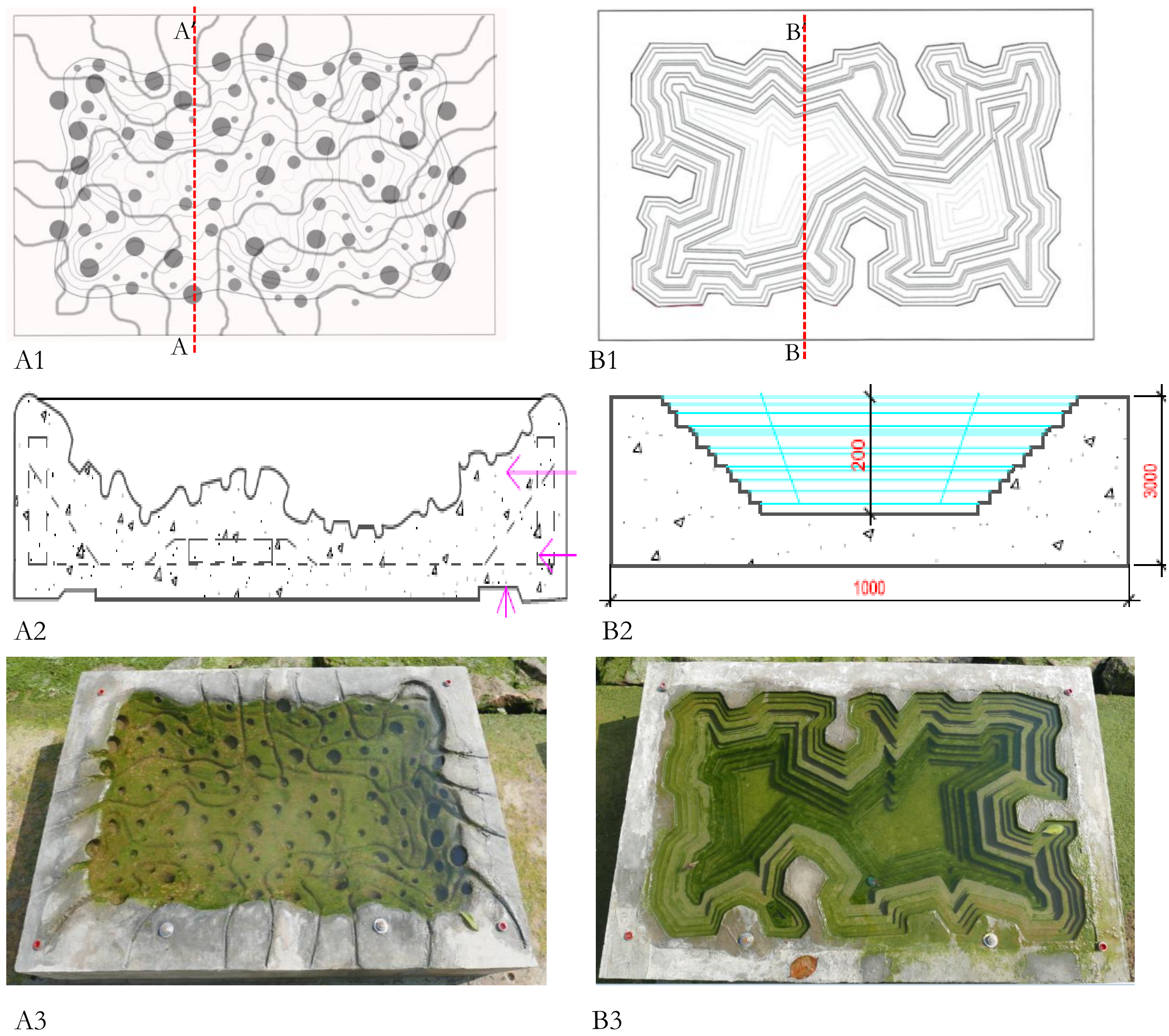
(3) the density of objects; and (4) the variability and range in the objects' dimensions, to design reverse-engineered tidal pool units to be introduced along an existing stretch of seawall with a barren horizontal surface.

These tidal pool units consisted of purpose-designed and fabricated concrete modules measuring 1.5 metres by 1.0 metre by 0.3 metre. They were fabricated with concrete suitable for the marine environment using negative fibreglass moulds, and were designed to collect seawater during high tide and to retain it during low tide to mimic a tidal pool environment. These tidal pool units were expected to create habitats that were similar to natural rock pools, to provide additional niches, and to encourage more diverse assemblages of marine organisms to thrive within the area.

To design the units, we first studied natural rock pool habitats to identify attributes that made them suitable for certain marine organisms to colonise and thrive, and found that a combination of crevices, grooves, and pits provided ideal niches and succession for a variety of marine organisms. These attributes were then incorporated in the design process, according to the four complexity parameters, to create conceptual designs that would most closely mimic natural tidal pool habitats. Multiple designs were created based on the different complexity combinations, and two designs were selected for testing.

The first design was a pool with a combination of evenly distributed grooves with pits of three sizes – 30 small pits (20-millimetre diameter), 30 medium pits (40-millimetre diameter) and 30 large pits (70-millimetre diameter) (Fig. 2A). The multiple sizes of the pits enabled us to increase the spatial scale of this feature. Pits and groves were cast on an inverted topographic surface. This surface plan mimicked a natural hilly landscape in Singapore (Central Catchment Nature Reserve), where the complex topography housed significant biodiversity.

The second design was a pool of the same rectilinear dimensions with a randomised arrangement of steps. The steps' thickness was calculated based on the aforementioned complexity parameters (Fig. 2B). The angular edges and offset create niches for marine organisms. We also embedded some pits (3-millimetre diameter) into some of the units of this design to test out the combination of pits and steps.



Figs. 2. (A) 1. Design of the pool with pits and grooves – Plan View; 2. Cross section A-A'; 3. Final cast of the pool with pits and grooves; (B) 1. Design of the pool with randomised steps – Plan View; 2. Cross section B-B'; 3. Final cast of the pool with randomised steps.

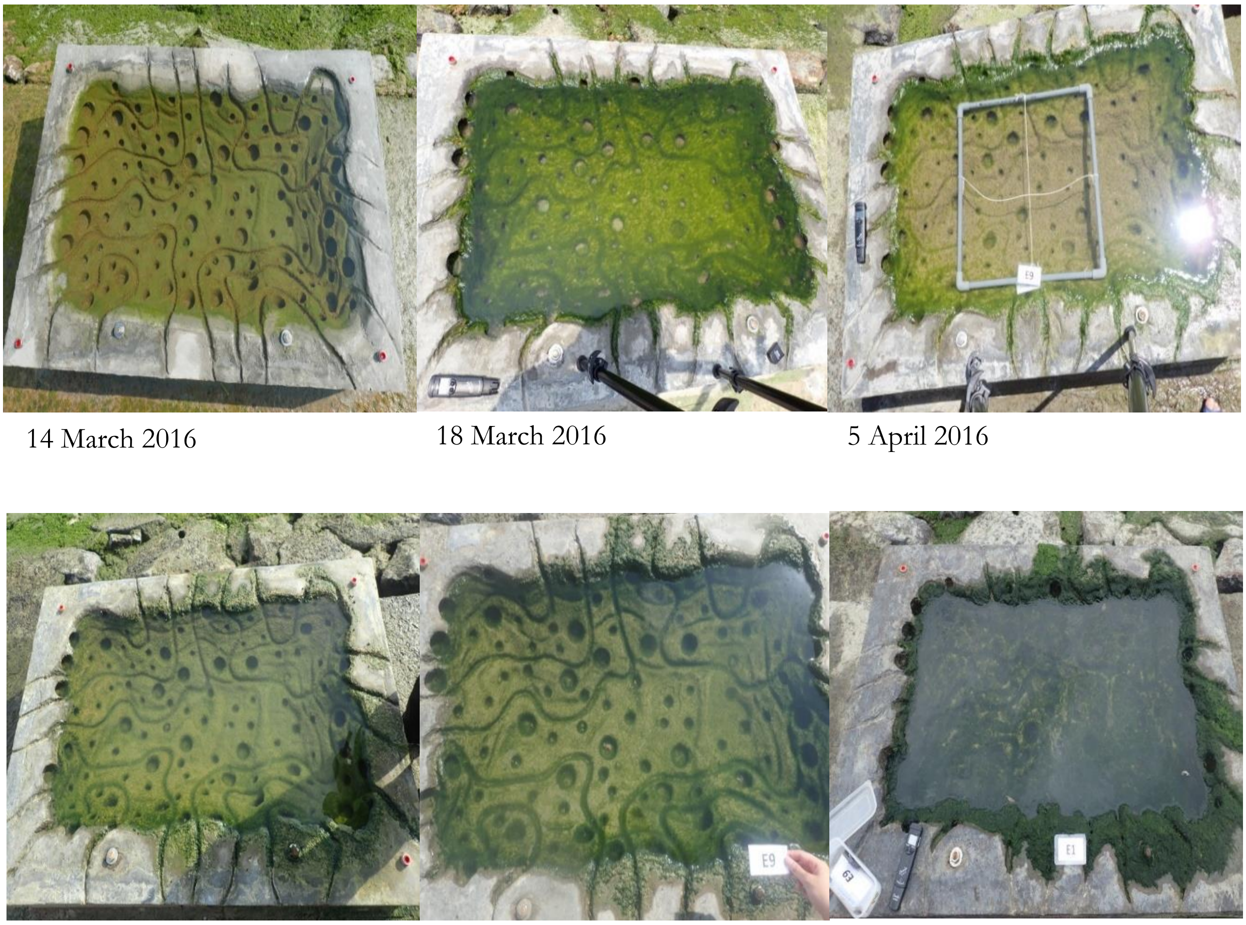
We studied the hydrodynamic conditions of the site that might affect the service life of the tidal-pool structures. Through hydrodynamic modelling, we calculated mean current speed and changes in bed thickness per year to identify whether the seawall was subjected to strong erosion or accretion. Mean current speed was also an indicator that helped determine if the coast was subjected to strong hydrodynamic forcing, that might result in lateral movement or even dislodgement of the fitted tidal pool structures. While there were studies suggesting that introduced artificial structures could have a positive impact on sandy shoreline stabilisation, the introduction of these structures should not compromise the ability of the engineered coastal infrastructure to perform its primary function. In the case of seawalls that were built for sea defence, the enhancement measures must preserve sea wall structural integrity, as well as connectivity of coastal processes.

We looked at the relationship between the tidal pool designs and community assemblage and succession by assessing their ability to provide shade and regulate temperature using drained and un-drained units. To reduce bias and account for treatment or site effect, we positioned the different design configurations randomly along a linear stretch of seawall and introduced control plots to assess the effectiveness of introduced structures versus no modifications. Control units in this context were empty plots on the seawall that were of the same size as the tidal pool units (Fig. 3). Data collected on these control plots would act as a baseline against which the treatments/modifications would be compared.

Fig. 3. The tidal pool units positioned in a randomised layout with control plots (empty slot without any tidal pool unit).

Results

The units were monitored fortnightly to gather data on the recruitment and succession of fauna and flora, as well as environmental parameters such as temperature, conductivity, and irradiance. We engaged a group of students from Nanyang Technological University to monitor and document the performance of the tidal pool units. Preliminary results indicated that the tidal pools were occupied by turf algae within the first week after installation and, shortly after, this single species was replaced by an assemblage of algae including *Bryopsis* spp., *Dictyota* sp., *Enteromorpha* spp., *Ceramiales* spp. and *Ceramium* spp. (Fig. 4). Fauna diversity and abundance increased over time and, after several weeks, we recorded periwinkle and nerite snails, crabs, tube and fire worms, feather stars, sponges, bead anemones, and even cuttlefish (Fig. 5). The performance of each tidal pool design and its complexity elements were also being monitored. The outcomes of this study were expected to provide a more comprehensive understanding of the combination of complexity treatments on species recruitment and biodiversity.



14 March 2016 | 18 March 2016 | 5 April 2016

26 April 2016 | 11 May 2016 | 31 May 2016

Figs. 4. Succession in unit E9 with contour designs.

Figs. 5. Marine organisms recorded in the tidal pool units.

Conclusions

Our results indicated that habitat enhancement of artificial coastal structures is one of the important strategies for biodiversity conservation in urbanised coasts. They also showed that by introducing appropriate substrates for the right environment, novel habitats could be created on shorelines with areas known to have low biodiversity. The performance of the habitat enhancement structures depended largely on the existing biophysical conditions as well as the structures to be enhanced. The conditions of the existing structures such as materials, inclinations, complexity, and exposure to human activities influenced the selection of suitable enhancement methods.

Projected sea level rise poses the most immediate threat to Singapore, and protecting our coastline has been identified as a priority in dealing with the effects of climate change. The current efforts to defend our coastal areas from erosion include the construction of walls and stone embankments. At the same time, ecologically informed engineering in the design and construction of coastal infrastructure would reduce loss of intertidal biodiversity on our artificial shoreline. Synergistically, the introduction of purpose-built coastal enhancement features would reduce the ecological impacts of future coastal protection and reclamation projects without compromising the functions of coastal defence structures.

Thus, the integration of engineering and ecological knowledge leading to the creation and modification of coastal structures that both protect the coast and better support biodiversity is an imperative win-win solution.

CHAPTER 23

Singapore Index on Cities' Biodiversity – A Monitoring Tool for Biodiversity Conservation Efforts

Jeremy Woon

Cities and biodiversity conservation

Despite occupying only 1–3% of the earth's surface (Liu *et al.*, 2014), cities consume about 60% of total global domestic material consumption (International Resource Panel, 2018). The ecological footprint of cities extends far beyond their boundaries, contributing significantly to biodiversity loss at the local and global levels. This issue is made more pressing by the fact that the majority of the world population will eventually reside in cities and urban areas. The proportion of the world population living in cities and towns is expected to increase from 54% in 2015 to 66% by 2050 (International Resource Panel, 2018). While this forecast presents numerous challenges, with the right measures in place, cities can be part of the solution. As urban populations grow, the role cities play in biodiversity conservation becomes increasingly important. Effective land-use and management of natural ecosystems within urban areas can be mutually beneficial to both residents and the biodiversity that exists within and around the city.

This potential to tap on cities as part of the solution was recognised by the Conference of Parties to the Convention on Biological Diversity (CBD) at its 9th Meeting in 2008. For the first time ever, Parties recognised the role of cities and local authorities in national strategies for biodiversity conservation through Decision IX/28, where national governments were encouraged to engage cities in national implementation of the CBD. During the High-Level Segment, Mr Mah Bow Tan, then Singapore's Minister for National Development, proposed the development of a biodiversity index for cities to benchmark conservation efforts and evaluate progress in reducing the rate of biodiversity loss.

Development of the Index

Following the proposal, the Secretariat of the CBD, in partnership with Singapore and the Global Partnership on Local and Subnational Action for Biodiversity, organised a series of expert workshops in 2009, 2010 and 2011 to develop the biodiversity index for cities. The workshops, attended by technical experts on urban biodiversity and ecology, international organisations, and city officials, discussed and identified indicators that would enable cities to monitor and evaluate their urban biodiversity conservation efforts. The outcome of the workshops was a User's Manual on the Singapore Index on Cities' Biodiversity (Chan *et al.*, 2014) which provided guidance on how to apply the index.

The Singapore Index on Cities' Biodiversity (or Singapore Index, also known as the City Biodiversity Index) was developed as a self-assessment tool that was easy for city officials to apply, scientifically credible, and served as an objective tool that was unbiased and could be applied by cities worldwide. It was designed to allow cities to benchmark and monitor the progress of biodiversity conservation efforts against their own individual baselines. The trends between periodical assessments of the index would show either an improvement or decline in the effectiveness of biodiversity conservation efforts by a particular city, and could be used to identify specific areas for improvement. It was intentionally designed not to become a tool for comparison between cities, due to inherent differences arising from locality. For example, cities in the temperate region would have an inherently lower biodiversity compared to tropical cities. The different sizes of cities would also mean varying biodiversity richness. A comparative global study of biodiversity in cities would have to stratify cities across several criteria.

The 10th anniversary of the first workshop on the development of the Singapore Index was in 2019. As the biodiversity landscape had evolved over the years since the index was developed, it was timely to initiate a review of the original indicators and to develop new indicators to take into account issues that had arisen, as well as to incorporate feedback from cities that had applied the index. The workshop on the Review of the Singapore Index on Cities' Biodiversity was held in Singapore in October 2019 with the following objectives:

(a) Develop new indicators to address gaps in the current indicators in the Singapore Index.

(b) Review the current indicators based on cities' feedback and to improve their applicability.

A Handbook on the Singapore Index on Cities' Biodiversity was published in 2021 (Chan *et al.*, 2021) with detailed instructions on how to calculate the updated indicators in the revised version of the Singapore Index.

Structure of the Index

The index comprises two parts: first, the "Profile of the City" which provides comprehensive background information on the city; second, a city's self-assessment using the 28 indicators based on the guidelines and methodology provided (Table 1). The scoring of the index is quantitative in nature. A maximum score of four has been allocated to each indicator, and with the current count of 28 indicators, the total possible score of the index is 112 points, where the individual scores of the 28 indicators are summed up to give the total score. The year in which a city first embarks on this scoring will be taken as the baseline year, and future applications of the index will be measured against this to chart its progress in conserving biodiversity.

Part I – Profile of the City

In addition to serving as an introduction, this section captures other relevant and useful information that provides a holistic picture of a city, and places its application of the indicators in the proper context. Here, a city provides information on its location, climate, size, demographics, economic parameters, physical characteristics, and biodiversity features. Expanding further on the biodiversity information, the city can include details of the ecosystems, populations of key taxonomic groups and the conservation status of these species.

Part II – Indicators

The 28 indicators are grouped under three broad components: native biodiversity in the city; ecosystem services; and governance and management of biodiversity. For each indicator, the rationale, calculation methods and possible data sources are stated clearly in a tabular format. Nine indicators have been selected to measure native biodiversity in the city, including proportion of natural areas in a city and changes in selected taxa, among others. Five indicators measure carbon storage and the cooling effect of vegetation and other ecosystem services in the city. Under good governance and management, fourteen indicators are listed, covering cities' biodiversity budgets, projects, collaborations, and partnerships. A large emphasis is placed on good governance and management to encourage proactive action by city officials who will be the ones applying the index.

Table 1. Overview of the Singapore Index on Cities' Biodiversity.

<table>
<tr><th colspan="4">SINGAPORE INDEX ON CITIES' BIODIVERSITY</th></tr>
<tr><td rowspan="7">PART I – Profile of the City</td><td colspan="3">Location and size (geographical coordinates (latitudes and longitudes); climate (temperate or tropical, etc.); rainfall/precipitation (range and average); including maps or satellite images where city boundaries are clearly defined)</td></tr>
<tr><td colspan="3">Physical features of the city (geography, altitude, area of impermeable surfaces, information on brownfield sites, etc.)</td></tr>
<tr><td colspan="3">Demographics (including total population and population density; the population of the region could also be included if appropriate, and for the purpose of placing it in the regional context)</td></tr>
<tr><td colspan="3">Economic parameters (Gross Domestic Product (GDP), Gross National Product (GNP), per capita income, key economic activities, drivers, and pressures on biodiversity)</td></tr>
<tr><td colspan="3">Biodiversity features (ecosystems within the city, species within the city, quantitative data on populations of key species of local importance, relevant qualitative biodiversity data)</td></tr>
<tr><td colspan="3">Administration of biodiversity (relevant information includes agencies and departments responsible for biodiversity; how natural areas are protected (through national parks, nature reserves, forest reserves, secured areas, parks, etc.))</td></tr>
<tr><td colspan="3">Links to relevant websites including the city's website, environmental or biodiversity themed websites, websites of agencies responsible for managing biodiversity</td></tr>
<tr><td rowspan="10">PART II – Indicators</td><th>Core Components</th><th>Indicators</th><th>Maximum Score</th></tr>
<tr><td rowspan="9">Native Biodiversity in the City</td><td>1. Proportion of Natural Areas in the City</td><td>4 points</td></tr>
<tr><td>2. Connectivity Measures or Ecological Networks to Counter Fragmentation</td><td>4 points</td></tr>
<tr><td>3. Native Biodiversity in Built Up Areas (Bird Species)</td><td>4 points</td></tr>
<tr><td>4. Change in Number of Vascular Plant Species</td><td>4 points</td></tr>
<tr><td>5. Change in Number of Native Bird Species</td><td>4 points</td></tr>
<tr><td>6. Change in Number of Native Arthropod Species</td><td>4 points</td></tr>
<tr><td>7. Habitat Restoration</td><td>4 points</td></tr>
<tr><td>8. Proportion of Protected Natural Areas</td><td>4 points</td></tr>
<tr><td>9. Proportion of Invasive Alien Species</td><td>4 points</td></tr>
</table>

Table 1. Overview of the Singapore Index on Cities' Biodiversity. *(Cont'd)*

	Core Components	Indicators	Maximum Score
PART II – Indicators	Ecosystem Services provided by Biodiversity	10. Regulation of Quantity of Water	4 points
		11. Climate Regulation – Benefits of Trees and Greenery	4 points
		12. Recreational Services	4 points
		13. Health and Wellbeing – Proximity/Accessibility to Parks	4 points
		14. Food Security Resilience – Urban Agriculture	4 points
	Governance and Management of Biodiversity	15. Institutional Capacity	4 points
		16. Budget Allocated to Biodiversity	4 points
		17. Policies, Rules and Regulations – Existence of Local Biodiversity Strategy and Action Plan	4 points
		18. Status of Natural Capital Assessment in the City	4 points
		19. State of Green and Blue Space Management Plans in the City	4 points
		20. Biodiversity Related Responses to Climate Change	4 points
		21. Policy and/or Incentives for Green Infrastructure as Nature-based Solutions	4 points
		22. Cross-sectoral and Inter-agency Collaborations	4 points
		23. Participation and Partnership: Existence of Formal or Informal Public Consultation Process Pertaining to Biodiversity Related Matters	4 points
		24. Participation and Partnership: Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organisations with which the City is Partnering in Biodiversity Activities, Projects and Programmes	4 points
		25. Number of Biodiversity Projects Implemented by the City Annually	4 points
		26. Education	4 points
		27. Awareness	4 points
		28. Community Science	4 points
	Native Biodiversity in the City (Sub-total for indicators 1–9)		**36 points**
	Ecosystem Services provided by Biodiversity (Sub-total for indicators 10–14)		**20 points**
	Governance and Management of Biodiversity (Sub-total for indicators 15–28)		**56 points**
	Maximum Total:		**112 points**

Habitat enhancement, restoration, and the Singapore Index

The availability and quality of habitats is one of the main determinants of how well biodiversity thrives in any environment, and much more so within the urban environment of cities. The Singapore Index has numerous indicators that directly or indirectly measure the outcomes of habitat enhancement and restoration. The following table presents the ways in which habitat enhancement and restoration efforts can be measured by the Singapore Index (Table 2).

Table 2. Ways habitat enhancement and restoration efforts can be measured by the Singapore Index

Indicators	**Habitat enhancement and restoration effects**
1. Proportion of Natural Areas in the City	This is a direct measure of how much natural areas a city has, and habitat enhancement and restoration would directly increase this figure.
2. Connectivity Measures	Connectivity between patches of natural areas in the Singapore Index is measured using specific criteria. Habitat enhancement and restoration can either help to merge patches under these criteria, or to physically connect patches.
3. Native Biodiversity in Built-up Areas (Bird Species)	This indicator measures biodiversity amidst the most urban areas. Enhancing and restoring habitats within such spaces would provide new areas or larger spaces and new sources of food that birds would be able to take advantage of.
4–6. Change in number of species in three taxa	The provision of new habitats presents opportunities for plants and animals that may not previously have been present in the city to take up residence by creating conditions that are conducive for them.
7. Habitat Restoration	This indicator directly measures the proportion of habitats restored as well as the types of habitats restored.
8. Proportion of Protected Natural Areas	Protected Natural Areas are areas of particular importance for biodiversity that are protected for the purpose of conserving it. Restoring or enhancing the existing habitats may help to improve the survivability of the important species for which it was originally protected, or to provide buffer areas to absorb some of the external impacts or re-direct human activities from the main Protected Area.
9. Proportion of Invasive Alien Species	Some invasive plant species can take over entire areas that were previously forested areas. When such areas are cleared, habitat enhancement and restoration can help to prevent the invasive plants from re-establishing, and thus contribute towards the eradication or management of these invasive species.
10. Regulation of Quantity of Water	This indicator measures the proportional area of permeable surfaces, including natural areas, or "effective impervious areas". Habitat enhancement and restoration have the potential to increase the area of natural permeable surfaces that can contribute towards this indicator.
11. Climate Regulation – Benefits of Trees and Greenery	This indicator is a direct measure of the tree canopy cover in a city, and if trees are planted in the habitat enhancement and restoration efforts, they would eventually contribute towards this indicator.

Table 2. Ways habitat enhancement and restoration efforts can be measured by the Singapore Index *(Cont'd)*

Indicators	**Habitat enhancement and restoration effects**
12. Recreational Services	This indicator measures the provision of green spaces available to residents of a city for recreational purposes. Habitat enhancement and restoration efforts create new areas that can then be made available to residents for recreation and thus contribute directly towards this indicator.
13. Health and Wellbeing – Proximity/Accessibility to Parks	The proximity and accessibility to parks are important elements of city planning that ensure green and blue spaces are available to all residents for recreation. Strategically planned habitat restoration and enhancement can increase the coverage of green areas that are accessible to the residents of a city.
16. Budget Allocated to Biodiversity	The budget allocated to biodiversity conservation purposes indicates a city's commitment towards this cause, and the budget used for habitat enhancement or restoration projects would contribute directly towards this indicator.
20. Biodiversity Related Responses to Climate Change	Habitat enhancement and restoration efforts can contribute to the implementation of plans for biodiversity-related responses to address climate change in the areas of adaptation, mitigation, or ecological resilience.
21. Policy and/or Incentives for Green Infrastructure as Nature-based Solutions	Habitat enhancement and restoration efforts can contribute as provision of green infrastructure in compliance with the policies, regulations, and incentives for nature-based solutions.
22. Cross-sectoral and Inter-agency Collaborations	Appropriate sites for habitat enhancement and restoration efforts are not always parked neatly under the jurisdiction of a single agency, and such efforts would involve coordination between various landowning agencies as well as the agency in charge of biodiversity or habitat enhancement. This also encourages the mainstreaming of biodiversity conservation.
24. Participation and Partnership: Number of Agencies/Private Companies/NGOs/Academic Institutions/International Organisations with which the City is Partnering in Biodiversity Activities, Projects and Programmes	Habitat enhancement and restoration projects provide an opportunity for engagement with a range of diverse organisations, in terms of land use permissions, design of the area to be enhanced or restored, engineering expertise, or even conducting tree planting activities as part of the project.
25. Number of Biodiversity Projects Implemented by the City Annually	This indicator is a count of the biodiversity related projects that the city is directly involved in. Habitat enhancement or restoration projects would contribute directly towards this indicator.

Table 2. Ways habitat enhancement and restoration efforts can be measured by the Singapore Index *(Cont'd)*

Indicators	**Habitat enhancement and restoration effects**
26. Education	Sites that have undergone enhancement or restoration can provide potential venues for schools to bring students on educational field trips, as part of the implementation of the curriculum, and directly contributing towards this indicator. Students can initiate habitat restoration and enhancement projects in their school grounds so that biodiversity conservation can be incorporated into the school curriculum in an active way.
27. Awareness	Sites that have undergone enhancement or restoration can provide potential venues for outreach events, which would facilitate this indicator directly.
28. Community Science	Citizen scientists can partake in habitat restoration and enhancement in numerous ways, through biodiversity monitoring activities, photography, etc. Sites that have undergone enhancement or restoration can provide potential venues for citizen science projects, thus increasing available opportunities and contributing directly to the indicator.

Conclusion

Cities, by their nature, will have had to clear significant portions of the original habitats that once existed in the area. Remaining habitats tend to be exposed to impacts that are associated with urbanisation, and have limited space in which they can expand. Thus, it is only with active human intervention that these habitats would be able to expand and thrive, to better provide ecosystem services to the residents of the city. With habitat enhancement and restoration efforts being highly relevant to the indicators of the Singapore Index, it shows that such activities are important in relation to conserving the remaining biodiversity of a city. For cities that place biodiversity conservation as a priority, the ability to track concrete outcomes of their habitat enhancement and restoration efforts would go a long way towards validating the initial investment in such activities.

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CHAPTER 24

Habitat Enhancement Aided by Geographic Information Systems (GIS)

Alex Yee

Geographic Information Systems (GIS) is an invaluable tool for habitat enhancement. It is a computer system to capture, store, analyse and visualise spatial data. In other words, GIS is not merely *the map* used for viewing, but also the system that handles the layers of digital information that forms *the map* (Fig. 1). In the context of habitat enhancement, one could use GIS to gain a better understanding of the parks and surrounding environment, make informed decisions on the approaches to adopt, and communicate the output with stakeholders. The aim of this chapter is to provide a basic overview of GIS, so one could work effectively with a GIS personnel in carrying out the habitat enhancement work.

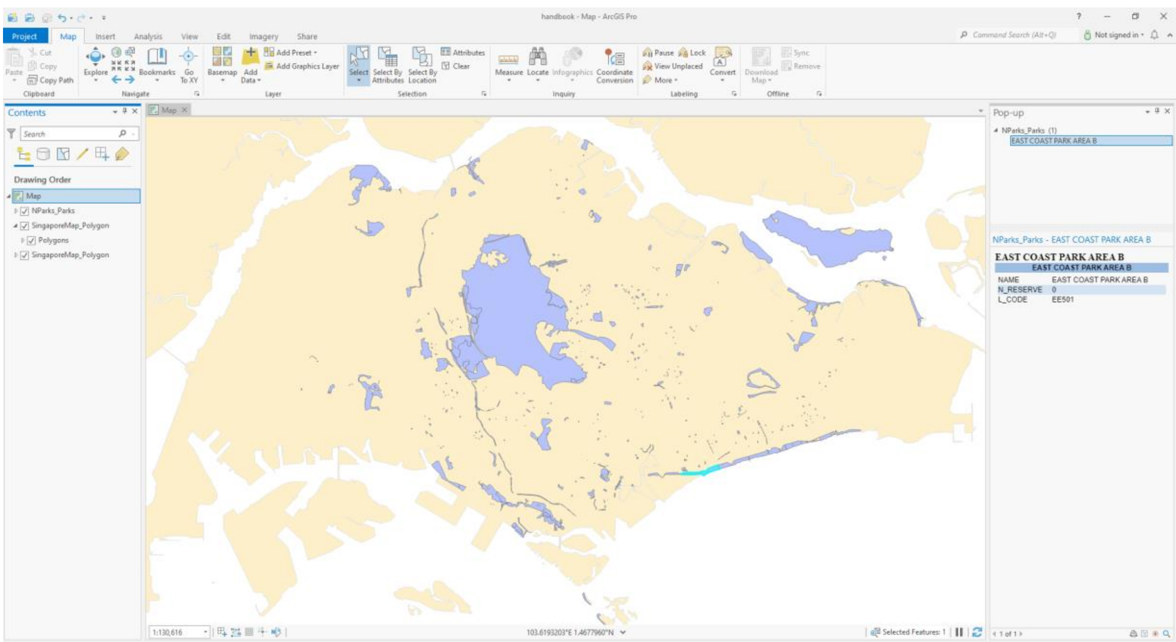

Fig. 1. Example of a GIS software interface that shows the Singapore islands and location of parks. A park was selected, and its related information was shown in the right panel.

There are some GIS operations to consider before starting a habitat enhancement project. Habitat mapping within the park and surrounding environment is the crucial first step for planning the habitat enhancement project. A key consideration for habitat mapping would be if the enhancement project is species-specific (e.g., for endangered butterflies) or non-species-specific (e.g., improving the overall canopy complexity of the area). Another preliminary consideration would be land cover such as grass/shrubs, trees, bare ground, water, and impervious surface (Fig. 2). Additional information can be added for refinement, such as height, quality, and composition of the land cover. If the project is species-specific, the team can consult taxonomic experts to conduct hotspot mapping or species distribution modelling to identify suitable areas for habitat enhancement.

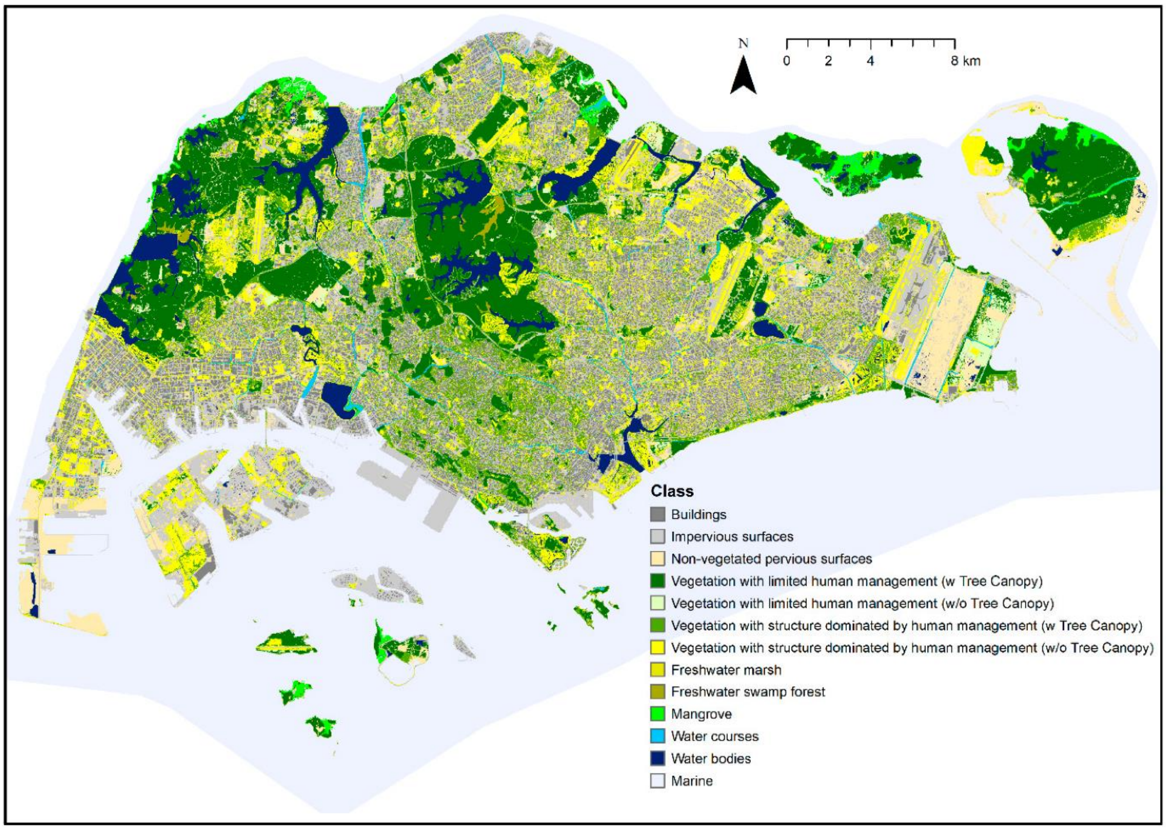

Fig. 2. An example of land cover map that can be used to represent habitat types. (Image credit: Gaw *et al.*, 2019)

Influence from the surrounding landscape would be an important factor to consider. This entails understanding if there are similar habitats in the proximity or identifying potential environment or anthropogenic stressors that need to be mitigated. This can be done in GIS by doing a buffer analysis, and its key component would be to identify a suitable buffer distance in view of the habitat enhancement objective. Examples of suitable buffer distance to consider are 126–500 metres for birds (Chong *et al.*, 2019; 2014; Wong *et al.*, 2023) and 50 metres for butterflies (Chong *et al.*, 2019).

Alternatively, one can measure via GIS the nearest distance to other habitat patches or features of interest.

Ecological connectivity. At times, the nearest distance might not be reflective of how the species could move and disperse into the habitat enhancement site owing to the presence of natural (e.g., water) or man-made (e.g., roads) barriers. The team can consider mapping the ecological connectivity of the species of interest via least-cost path analysis or similar techniques (e.g., circuit theory). This usually involves identifying the barriers in the landscape and assigning a "resistance cost" to the features. It is recommended to consult ecology or taxonomic experts to conduct this type of analysis.

Other factors to discuss with the GIS personnel include:

Software. Many commercial and free options are available. The hardware and infrastructure requirements as well as the type of GIS analysis and visualisation that they could perform should be taken into consideration. Recent advancement has also facilitated the development of interactive maps for better visual communication with stakeholders.

Data. Key questions for assessing the resources required for the GIS work:

(1) What data are needed for me to make informed decisions?

(2) Are the data available in the right format, geometry, scale, and coordinate system?

(3) When were the data acquired or last updated?

(4) What is the most effective way to acquire new data?

Data acquisition. Satellite imageries, especially those containing multispectral bands, have been frequently used to derive the land and vegetation features, although very high-resolution images (0.3 to 2 metres) would need to be purchased. Drone imagery has been increasingly used and regulations are changed regularly. It would be prudent to check with the relevant authorities on the latest regulation. Data can also be collected on the ground, such as commissioning a topographic survey for very accurate and precise geospatial data, or simply using a handheld Global Positioning System (GPS) device or smartphone for a coarser mapping.

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CHAPTER 25

Naturalising our Parks Framework

Ong Chong Ren, Jason Wright, Afiq Fairuz, Kartini Omar & Kee Wen Yu

Objective of the Framework

Imagine relaxing in a park immersed in nature with lush greenery and nature-based activities around you where you can feel the positive energy to your physical and mental well-being. Transforming to a City in Nature, towards a more liveable, sustainable and resilient Singapore, requires a paradigm shift on how we plan, design, develop and manage our green spaces. NParks has put together a framework to enhance the naturalisation of our parks and gardens, which is being applied to our parks and development projects.

Approach to Naturalising our Parks

When the British arrived in Singapore in 1819, Singapore was covered with rainforest, swamps, and mangroves. By 1900, 90% of the primeval forest had been cleared and exploited for timber extraction, agriculture, and the creation of settlements. While the British designated forest reserves and nature reserves, much of these areas were eventually replaced by plantations and agriculture, leaving only small reserves scattered across the island. Today, Singapore is home to over 300 parks with a variety of coastal, riverine, forest and urban habitats. Each park has a unique natural history ranging from largely undisturbed by human interference to completely transformed by human activities. In attempting to naturalise our parks, each park requires a tailored approach based on factors that include the current ecological condition of the site, the historical habitat type and the natural processes that supported the historical habitat.

The paper entitled Managing the whole landscape: historical, hybrid, and novel ecosystems (Hobbs *et al*., 2014) gave direction on appropriate habitat restoration. The paper identified the issue of landscapes being increasingly composed of ecosystems that have been altered to varying degrees, thus requiring different approaches on how to intervene. It recommends moving away from the traditional approach of partitioning landscapes into dichotomous categories (e.g., natural/unnatural, intact/degraded) and instead to see landscapes as a complex mosaic of ecosystems in varying states of modification.

NParks' framework to naturalise parks and gardens proposes three nature restoration intervention models or goals, namely natural, novel and hybrid landscapes. Natural landscapes comprise habitats that have largely retained their natural ecosystems spanning over a significant period with minimal intervention by humans. Examples in Singapore include the mature secondary forests around the Bukit Timah Nature Reserve and Central Catchment Nature Reserve and wetlands at Sungei Buloh. These natural landscapes provide the greatest potential to restore nature to the predevelopment state through targeted restoration techniques such as species recovery programmes. Rifle Range Nature Park outlined later in this chapter is one such example.

Novel landscapes comprise habitats that have largely been disturbed by humans and therefore the ecological processes that supported that historical habitat are largely degraded. An example in Singapore is Jurong Lake Gardens which was formerly a freshwater mangrove swamp before it was cleared and levelled in the 1960s for industrial developments. When ecological processes have changed beyond the point of being feasibly restored, such as the hydrology at Jurong Lake Gardens, it might no longer be possible to restore the site to its predevelopment state. Instead, restoration goals should take a new direction to create alternative habitat types. Jurong Lake Gardens outlined later in this chapter is one such example.

Hybrid landscapes are similar to novel landscapes in that they have largely been disturbed by humans. However the difference is that the ecological processes that supported that historical habitat can partially be restored. Pasir Ris Park which is featured in Chapter 21 is an example of a hybrid landscape which historically consisted of a mangrove forest until land reclamation works in the 1970s severely degraded the habitat. Restoration took place in 2001 to replant the mangroves, but was only limited to areas which were feasible to do so due to the constraints in restoring the site's hydrology. Hybrid landscapes restoration comprises a mosaic of habitat types depending on the level of ecological process restoration. Bukit Canberra outlined later in this chapter is another example.

The Three Phases of the Framework

The process of naturalising our parks requires a sustained effort that starts from the onset of planning for the parks all the way to the day-to-day management and running of the parks after the development phase. The framework to naturalise our parks covers the full range of efforts required during the Planning Phase, Implementation Phase and Programmatic Phase.

The Planning Phase involves identifying the goals of restoration with a detailed analysis of the site, which is done at both the macro and micro levels. Macro level analysis includes researching the wider historical, ecological connectivity and land use layers. Micro level analysis includes researching the site's topography, biodiversity and microclimate layers. Once the analysis is completed and there is a full understanding of the site's past and present, it is then possible to identify the goals of restoration i.e., natural, novel or hybrid.

The Implementation Phase involves three steps. The first step is to establish that the ecological processes that support the desired habitat can be restored and/or created, which can include modifying the hydrology, topography, soil composition, etc. The second step involves ways to restore/create the habitats, which includes determining the vegetation structure such as planting in multi-tiers to create a rainforest structure. It also includes identifying key flora and fauna species to help in species recovery programmes. The third step involves ecological aesthetics, which entails creating immersive nature experiences for visitors to enjoy, and therefore requires design considerations to maximise the habitat's attractiveness to visitors.

The Programmatic Phase involves the hardware and software to activate the park, add vibrancy and help connect visitors with nature in a variety of exciting ways. The hardware includes sensitively incorporating features such as nature playgardens, therapeutic gardens and nature fitness areas. The software includes NParks' community programmes such as Community in Bloom, Friends of the Park and the OneMillionTree movement. Planning for these programmes at the project inception stage ensures all the relevant infrastructures are in place to support the activities once construction is completed.

Naturalising our Parks Framework Checklist

To help guide practitioners that include designers, project managers, landscape architects and horticulturists to naturalise green landscapes, a checklist as part of the Naturalising our Parks Framework has been created. The checklist provides a comprehensive guide on the information, steps and processes involved, such as information needed for the site analysis, design considerations as well as implementation strategies at construction stage, and outreach and engagement programmes that follow, to achieve the goals of restoration. The checklist is intended to be a document that follows the planning, development and management of the park to guide and provide the various thought processes to realise the project's goal of restoration. The checklist can be found in Annex A.

Case Studies

To demonstrate the operationalisation of the three phases of the framework as well as the three goals of restoration, three case study projects are outlined below.

Rifle Range Nature Park: Case study model for natural landscapes

Rifle Range Nature Park is a 66-hectare nature park located at the southern end of Bukit Timah Nature Reserve. The park serves as an important buffer to the Bukit Timah Hill, Singapore's highest hill, which remains one of the few areas of primary rainforest and home to around 40% of Singapore's native flora and fauna. As a buffer park, Rifle Range Nature Park provides not only habitat for native fauna but also food sources for them to survive on. This park development was part of a holistic approach to strengthen the conservation of the biodiversity in Singapore's nature reserves while providing interesting alternative venues for the public to enjoy nature-related activities in the city-state.

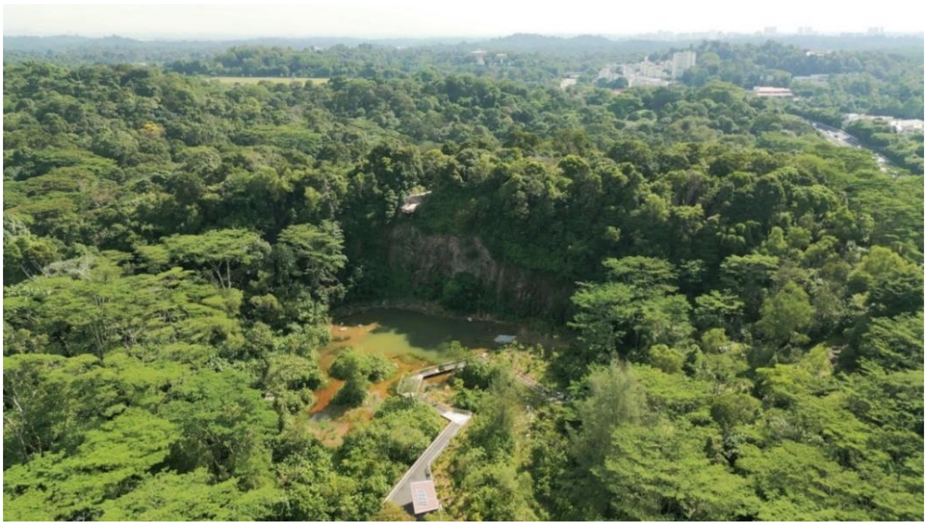


Fig. 1. View from the Colugo Deck at Rifle Range Nature Park.

The key challenges for the nature-sensitive project were to find a point of balance between the development for recreational uses and conservation of biodiversity based on data-driven, science-based approach at all stages of the park development.

Planning Stage

From the early stages of the park's planning, a clear goal of restoring the natural historical ecosystems had been established. Historically, the site was a granite hill with secondary forests, villages, and past quarrying activities from the 1950s to the 1980s. By the 1990s, quarrying activities stopped and the quarry was backfilled. Villagers were also resettled as a result of this closure. With decades of minimal human intervention, species of flora and fauna from the Bukit Timah Nature Reserve have since established themselves in the Nature Park. The clear goal of restoration served as an important guide in the making of the nature park as the decisions to protect ecological habitats were prioritised over recreational needs.

The planning and design of Rifle Range Nature Park were heavily driven by scientific data. As the site is an existing forest, areas of high biodiversity and large trees of conservation significance needed to be identified and protected even before works to design the park commenced. A nine-month long biodiversity study was commissioned to document and map out the floristic and fauna diversity of the 66-hectare site. The study entailed line-transect surveys of over 10 kilometres conducted by systematically walking the site and recording sightings of flora and fauna, plot sampling, and deployment of over 110 camera traps strategically placed throughout the forest. The camera traps were programmed to be active 24-hours a day at high sensitivity to collect video footages when triggered by movement or changes in temperature. This detailed baseline study at the planning stage was fundamental for the subsequent design and implementation of the park.

Implementation Stage

A site-sensitive approach was adopted during the development of the park. With an accurate inventory of flora and fauna data collected and geo-mapped from the baseline study (Fig. 2), the design consultants comprising architects, engineers, geotechnical specialists, landscape architects and builders were able to provide site-sensitive solutions. They worked as a team with the biodiversity researchers to ensure that development works avoided important ecological habitats and catered animal-specific design solutions to enhance ecological connectivity in the park (Fig. 3).

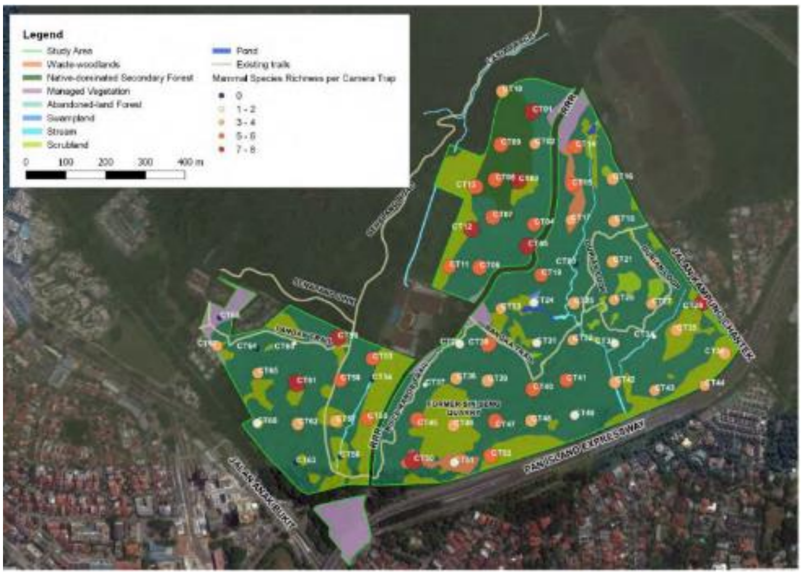


Fig. 2. Mammal Species Richness overlaid on Vegetation Map. (Image credit: Camphora Pte. Ltd.)

Figs. 3. Prototyping and Installation of Aerial rope bridges and Colugo Poles.

Throughout the construction of the park, conscious efforts were made to collect biodiversity data, with an Environmental Mitigation and Monitoring Plan (EMMP) being put in place to proactively manage any impacts of construction activities to ensure that the stipulated Environmental Quality Objectives (EQOs) for the project were not exceeded.

The park visitors' experience was designed with biophilia in mind, that, according to biologist E.O. Wilson, was an innate and genetically determined affinity of human beings with nature. The design sought to capitalise on and bring out the beauty of the site's existing terrain and hydrology. From the Rambai Boardwalk entrance to the Bayan Trail exit, the journey was curated for visitors to feel close to nature. The park starts with an invigorating experience along the wheelchair-accessible Rambai Boardwalk (Fig. 4). Any visitor can instantly escape from the hustle and bustle of the Beauty World precinct into a rejuvenating young secondary forest surrounded by the calls of native birds such as the endangered Straw-headed Bulbul (*Pycnonotus zeylanicus*). With the carefully designed earth trails, visitors can feel the natural undulating earth beneath and may be able to chance upon native fauna species such as the Sunda Pangolin (*Manis javanica*) and Horsfield's Flying Squirrel (*Lomys horsfieldii*). Native crabs, frogs, fishes, and snakes may also be spotted at the slow-flowing sandy Banyan Stream crossing.

Fig. 4. Rambai Boardwalk from the Beauty World Precinct.

A hike up the challenging quarry trail will take adventure seekers up to the Colugo Deck, a vantage point that hangs over the 50-metre high granite quarry cliff and overlooks the freshwater quarry wetland (Fig. 5). The park development took the opportunity to create a freshwater habitat from the former backfilled quarry for marsh birds and aquatic animals. Overall, the park was designed and built for interesting encounters with native flora and fauna, so that visitors can feel at one with nature.

Fig. 5. Freshwater quarry wetland at Rifle Range Nature Park.

Programmatic Stage

A long-term effort to monitor biodiversity in the operation phase of Rifle Range Nature Park has been catered for with animal-monitoring CCTVs placed at strategic locations of the park (Fig. 6). This is part of a science-based approach to provide valuable data for continued research in native flora and fauna, and also engages visitors to learn and appreciate the importance of native biodiversity and efforts towards ecological conservation. The Roadway Animal Detection System (RADS) has also been installed along Rifle Range Road. RADS is an advanced form of an animal detection system that uses CCTV cameras enabled by Artificial Intelligence (AI). When animals are detected, RADS alerts motorists by activating blinking signages to react and take the necessary precautions, such as reducing vehicular speed and exercising heightened vigilance. This technology aims to reduce road kill incidents in the long run.

Fig. 6. Animal monitoring camera installed on Arboreal Crossing for long term biodiversity monitoring.

Nature-sensitive programmatic planning is important for Rifle Range Nature Park to engage, educate and involve communities to help with nature conservation. The Invasive Species Management (ISM) is a programme that involves residents and the nature community to help weed out invasive alien species as the threat they cause is ever-increasing if left unmanaged (Fig. 7). To help the propagation of native flora, a Community Nursery has been built at the park for volunteers to help with the propagation of native plants in the park.

Fig. 7. Community involvement in invasive species management.

Jurong Lake Gardens: Case study model for novel landscapes

Jurong Lake Gardens is Singapore's third national gardens, and is situated within the heartlands. It is a people's garden, where spaces are landscaped and created for families and the community to come together for leisure and recreation amidst lush greenery and scenic lakeside setting. The design and development of the Garden take into consideration suggestions from the community through extensive public consultation (Fig. 8). The 90-hectare Gardens comprise Lakeside Garden, Chinese Garden, Japanese Garden, and Garden Promenade. The 60-hectare Lakeside Garden opened in two phases to the public in April 2019 and April 2023, focusing on the themes of nature, play and the community. The remaining 30 hectares, comprising Chinese Garden, Japanese Garden and Garden Promenade, focus on the themes of tropical horticulture, garden artistry, and sustainability and technology. The Gardens as a whole exemplifies NParks City in Nature vision, and have emerged as a model for the enhancement and landscaping of novel habitats in urban environments.

Fig. 8. Visitors enjoying the tranquil sunrise at Rasau Walk at Lakeside Garden.

Planning Stage

The original habitat of the Jurong area consisted of freshwater swamp and mangrove habitats flanking the banks of Sungei Jurong. During the 1970s, these habitats were cleared to give way to factories and urban areas as part of Singapore's industrialisation efforts. Today, the only remaining natural freshwater swamp habitat is found at Nee Soon Swamp Forest in the Central Catchment Nature Reserve. One of the key planning considerations for Jurong Lake Gardens was the implementation of a Garden-wide habitat creation masterplan (Fig. 9), within which the re-creation of freshwater swamp habitats was imperative. Large mature Ficus trees along the shoreline were retained as they serve as keystone species providing food and shelter to a wide range of birds. A comprehensive biodiversity survey was also undertaken to identify significant areas of vegetation rich in bird life. These areas were conserved and protected, and buffer woodland planting was implemented to reinforce the integrity of these important nodes. Connectivity with adjacent natural areas was also carefully studied as part of landscape planning. Areas abutting Nature Ways along Yuan Ching Road and Boon Lay Way were planted with complementary vegetation to enhance these green spaces as corridors for the movement of biodiversity.

The conversion to an urban environment in the Jurong area had been very significant, resulting in higher temperature fluctuations and reduced humidity in many exposed areas where vegetation had been cleared. As part of the biodiversity study conducted for the Jurong Lake District, biodiversity hotspots were identified within the district (Fig. 9), and novel habitats planned as part of the habitat creation masterplan (Fig. 10). A good example of this was the grasslands, where six different species of grasses were planted in a 3.5-hectare open area devoid of tree cover to provide habitat for a wide range of grassland birds. The success of these efforts is evident from the ubiquitous flocks of Scaly-breasted Munias (*Lonchura punctulata*) that frequent the tufts of grasses, as well as sightings of the Zitting Cisticola (*Cisticola juncidis*) in search of grass seeds.

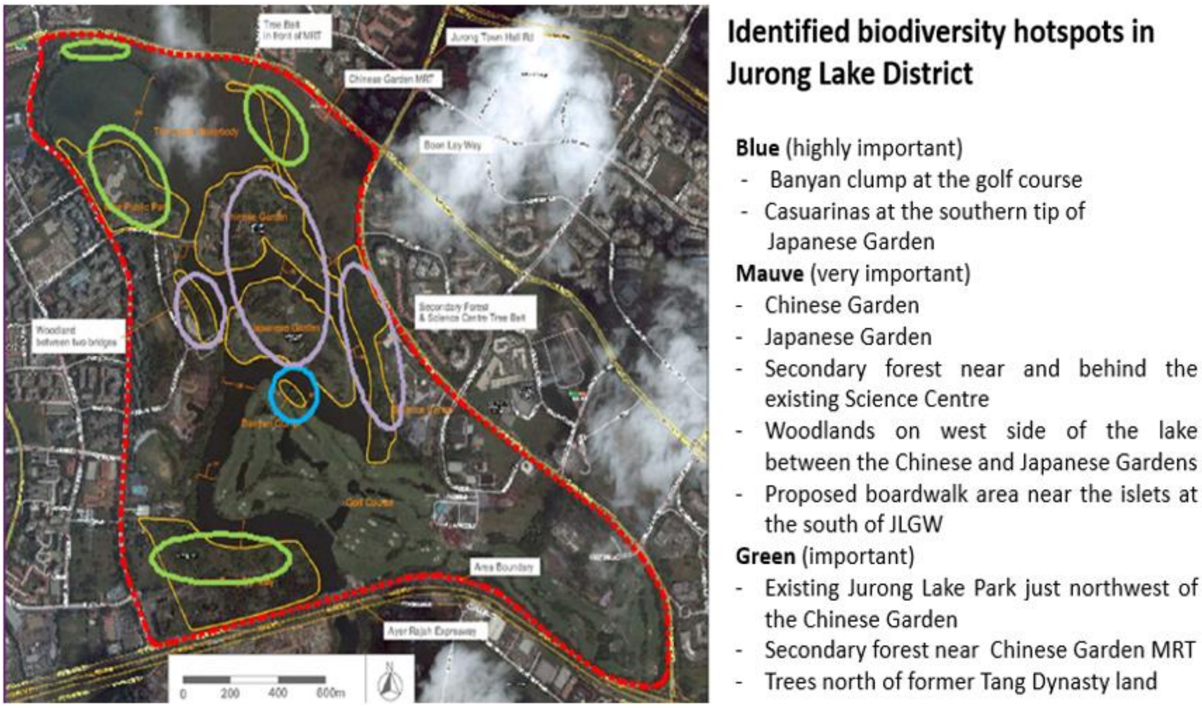


Fig. 9. Identified biodiversity hotspots in Jurong Lake District.

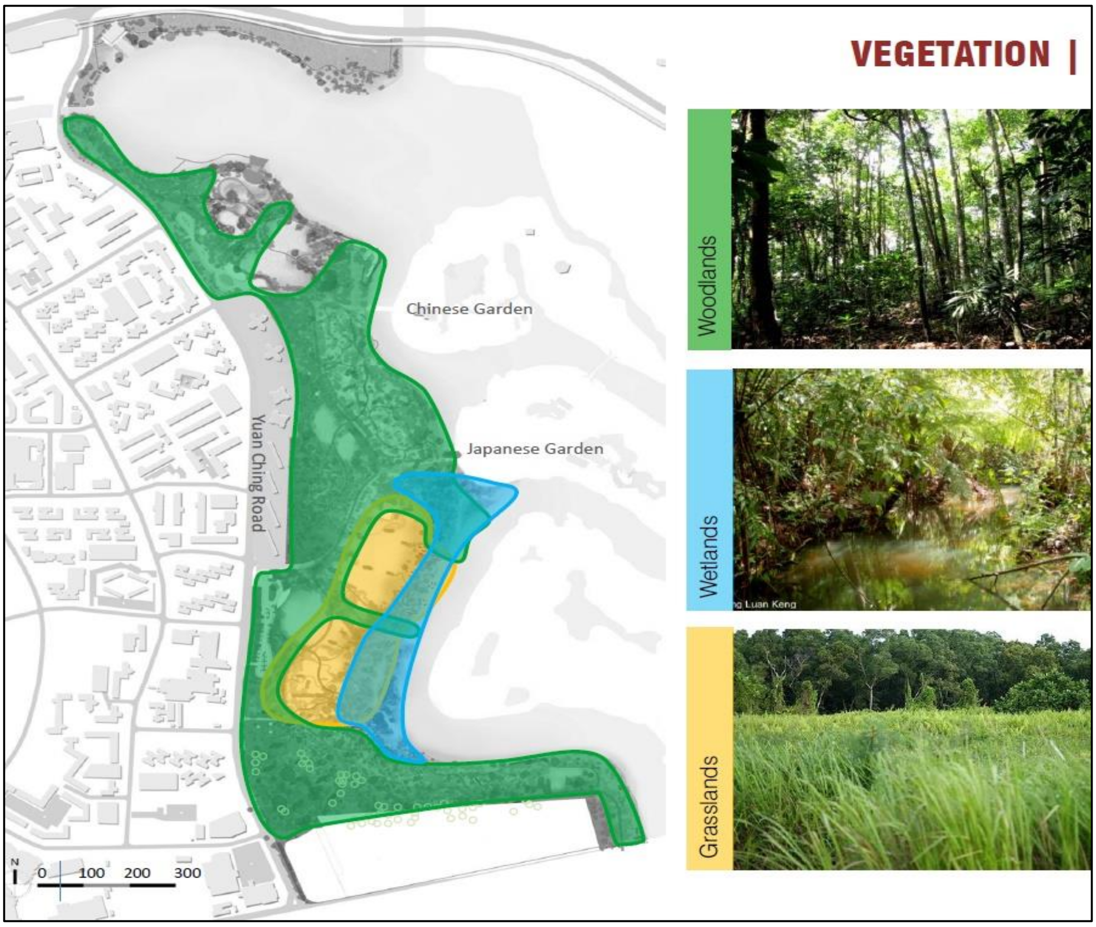


Fig. 10. Novel habitats within Lakeside Garden.

Implementation Stage

Some of the most visible landmarks within Jurong Lake Gardens were the large, vegetated swales running from the west of Lakeside Garden towards Jurong Lake. These swales were conceived as a mitigation solution to manage the high water table of the site. During the planning phase, hydrological and topographical analyses revealed that almost the entire site was low-lying, with significant water logging situations in areas in the north and south of the site. To mitigate these issues, swales were implemented to drain the site and lower the level of the water table. One prominent example where this was done was the creation of Neram Streams, where an existing 300-metre long concrete monsoon canal was de-concretised and de-canalised to create a series of braided, naturalised and vegetated streams that reduce the speed of surface runoff and cleanse the water discharged from upstream urban catchments before being discharged into Jurong Lake (Fig. 11). These swales now serve as habitat for a wide range of dragonflies, damselflies and other aquatic and riparian species.

Fig. 11. Creation of Neram Streams by transforming a 300-metre concrete canal into a series of braided, naturalised and vegetated streams.

Ecological aesthetics was another area in which significant emphasis was placed during the landscaping of the Gardens. To achieve this, landscape planning was performed on a broad scale. To complement the activity levels of spaces within the gardens, the landscape theme was planned with ornamental planting in the northern active zones gradually giving way to native planting in biodiversity-rich areas towards the south. Colour was also an important consideration in species selection. A ribbon of pink-flowering trees and shrubs was planted along the park connector network spine stretching from north to south, and also along the shoreline to create splashes of colour along the waterfront (Fig. 12). Trees and shrubs were planted to emulate natural growth habits in nature, by varying the heights of trees and shrubs within clusters, and also by considering carefully the layering of vegetation to mimic the natural vegetation strata in forests. More than 3,000 existing trees were conserved on the site and over 200 transplanted, to form a connected corridor for wildlife and biodiversity. As part of species recovery efforts, native orchids such as *Cymbidium finlaysonianum* were also planted on mature rain trees.

Fig. 12. Ribbon of pink-flowering trees along park connector network spine and Lakeside Garden waterfront.

A third key feature of Jurong Lake Garden's implementation was the deliberate intention to create opportunities for biophilic experiences. One good example is the Forest Ramble, which is also Singapore's largest nature playgarden, where the individual play equipment sets were inspired by the actions and movements of animals that live within a freshwater swamp forest (Fig. 13). In using the play equipment, children emulate the motions of native swamp forest animals, resulting in the play experience being enriching and educational at the same time. Another example is the Rasau Walk, which is a 300-metre long boardwalk designed to bring people closer to the waterfront where a wide range of shorebirds frequently forage for food.

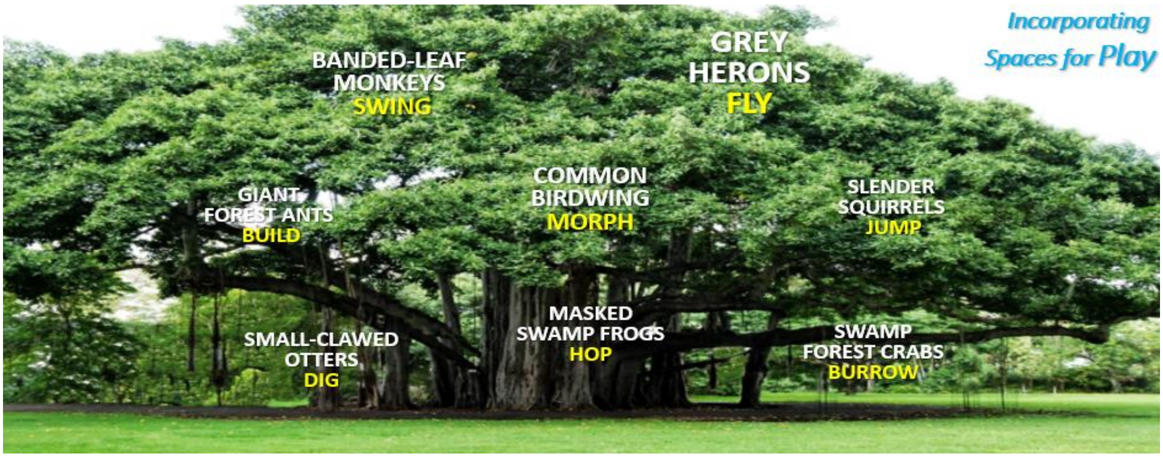


Fig. 13. Design consideration for playground elements at Forest Ramble for biophilic experiences.

Sustainability and Technology also form one of the key themes of Jurong Lake Gardens. A Sustainability and Technology masterplan was formulated with eight focus areas to guide the development of the gardens (Fig. 14), and to support Whole-of-Government efforts in line with the Singapore Green Plan 2030. An integrated management system consisting of a suite of environmental and facilities management sensors integrated to a central monitoring and control platform was also implemented to enhance situational awareness in day-to-day operations. The Gardens also actively serves as NParks' living lab for new technologies, ranging from robotics and automation to the use of sustainable building materials.

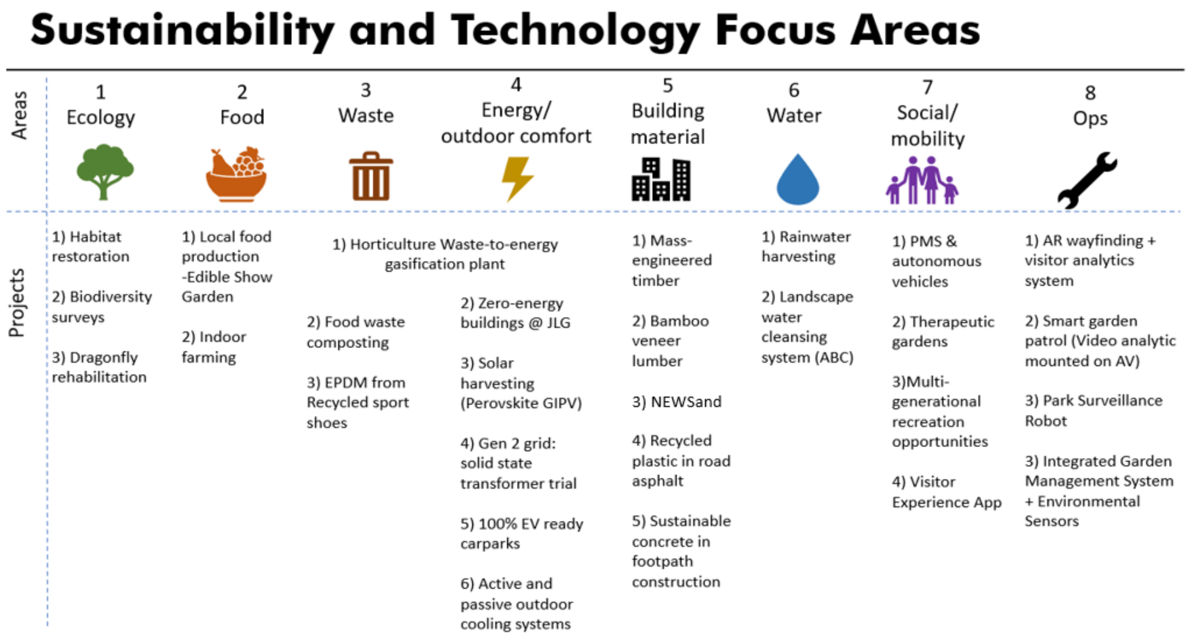


Fig. 14. Jurong Lake Gardens' sustainability and technology focus areas.

Programmatic Stage

Programmes within the Gardens are carefully curated to complement the Gardens' themes. Jurong Lake Gardens serves as the venue for events such as the Singapore Garden Festival Horticulture Show, Sustainable Festival as well as Mid-Autumn Festival. Regular programmes include activities such as nature guided walks and workshops that allow participants to learn about freshwater swamp forest habitats as well as native bird life. Activities such as composting workshops and Sustainable Festival also contribute towards increased environmental awareness.

Lakeside Garden houses Singapore's largest allotment garden, with 300 plots fully subscribed by local residents to grow their own fruits and vegetables. In December 2021, Singapore's largest therapeutic garden was opened, and it was also the first therapeutic garden to feature a children's zone designed and planted to cater to the needs of children with autism as well as seniors with dementia.

Bukit Canberra: Case study model for hybrid landscapes

Bukit Canberra, a vibrant and accessible 12-hectare integrated community hub is well interspersed with new habitats as well as a restored 1.5 hectares of secondary forest (Fig. 15). Bukit Canberra had been modified through the introduction and compounding of new planting strategies into the natural and historical sites. These approaches accompanied with nature-based solutions were the key strategies that identified this development's status as a restored hybrid landscape system. This project is being developed in stages.

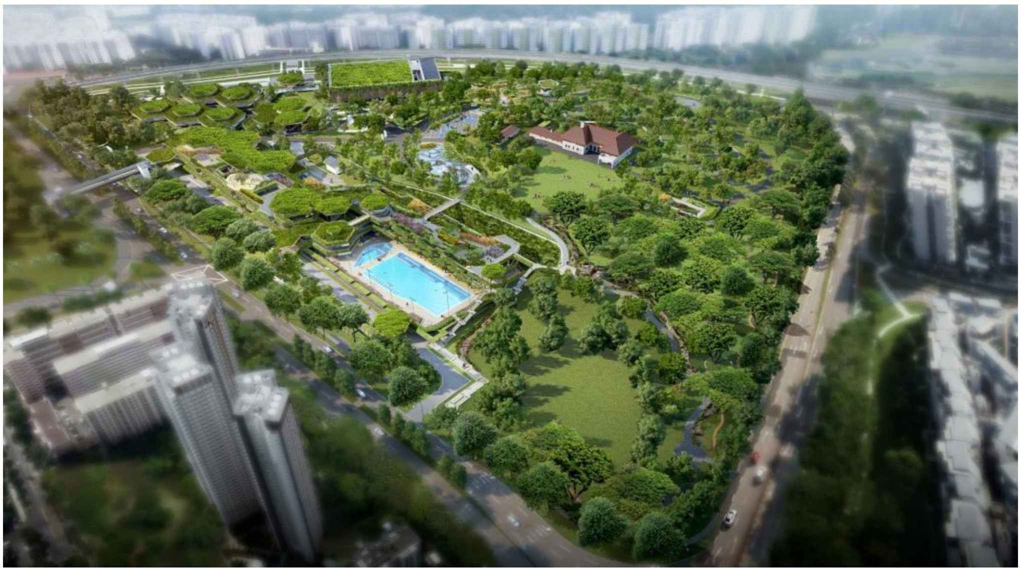


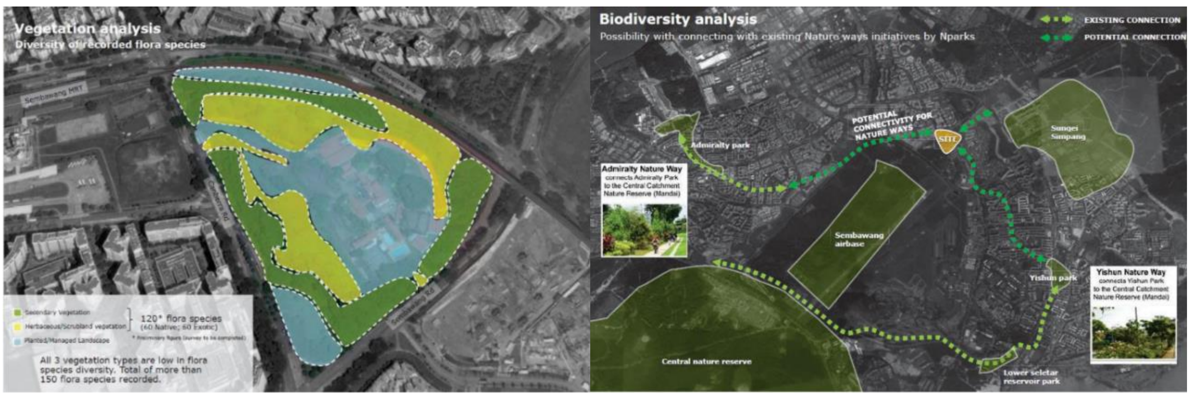
Fig. 15. Artist impression overview of Bukit Canberra integrated community hub. (Photo credit: SportSg)

In the early 1800s, Bukit Canberra's ecology comprised an array of habitats within an undisturbed primary rainforest. From the mid-1800s, the rich ecology of the site's surrounding areas made way for gambier and pepper plantations before rubber and pineapple plantations took over in the 1900s. In 1939, Canberra House was built on the site's hilltop. Despite rapid urbanisation of the site and its surroundings, some patches of regenerated secondary forest were found remaining at Bukit Canberra. Today, the enhancement plans include not only restoring but also reinterpreting the natural heritage of the site.

Planning Stage

Historical maps were used to identify past habitat types, vegetation types and natural heritage significance before determining the level of ecological restoration to be carried out at Bukit Canberra. Accompanied by a comprehensive analysis on the existing flora and fauna, identifying ecological connections for biodiversity conservation was prioritised for the Bukit Canberra site.

Three main vegetation types were found: secondary forest, herbaceous scrubland, and planted and managed vegetation (Fig. 16). A total of more than 150 flora species were recorded in all three areas. Within the secondary forest vegetation, there were exotic and native species, with more native species found on the southwestern and southeastern side of Bukit Canberra. While this area had a low to moderate sensitivity value, a few species of conservation status such as *Oxyceros longiflorus*, *Guioa pubescens*, *Litsea firma*, *Cyathea laterobosa* and *Pouteria obovata* were found. The scrubland vegetation was generally low in flora species and was mainly dominated by exotic grass species such as *Imperata cylindrica* and the native grass species such as *Ischaemum muticum*. Lastly, for the planted and managed landscape, more than 40 out of 150 flora species were exotic.



Figs. 16. Contextual mapping of vegetation types. (Image credit: SportSG)

The macro level analysis revealed existing Nature Way connections and ecological stepping stones in close proximity such as at Admiralty Park, Sungei Simpang and Central Nature Reserve. Identifying these connectivity considerations in the planning stage was crucial in strategizing new habitat creation at Bukit Canberra allowing it to contribute to habitat defragmentation effort.

Fig. 17. Mapping of habitat zones within Bukit Canberra. (Image credit: SportSG)

With the above ecological studies of the site, various habitat zones were planned throughout the entire development (Fig. 17). As most of the built forms would be developed within the Urban Zone, the habitat zones were strategized to minimize any stark contrast in landscape character between these built and landscape areas (Fig. 18). The existing secondary forest edge was retained and further enhanced progressively into a lush and dense forest buffer. A riparian habitat was planned to maximise water catchment, slow down water runoff and continue into the built areas in the form of vegetated swales and bioswales. Food forests and woodlands were also planned to encourage pollination cycle through the help of bees and other biotic pollinators. Finally, grassland habitat, that would mostly consist of either flowering shrubs or grasses, would provide foraging areas for grass-dependent bird species.

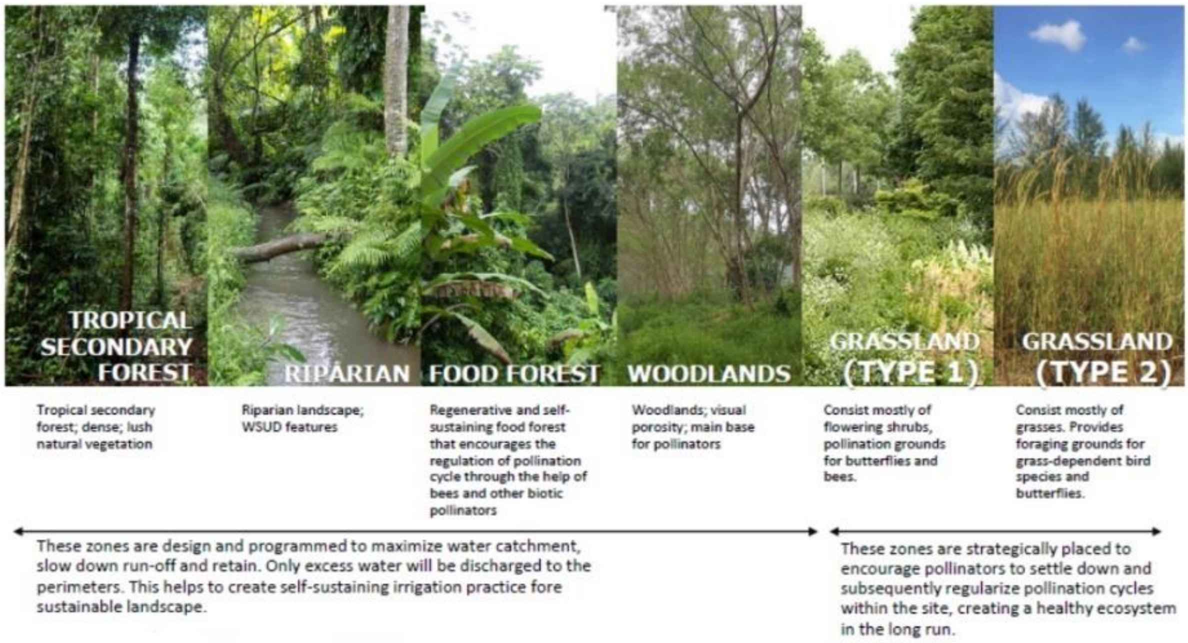


Fig. 18. This is an artist impression of the zones produced by the consultancy. (Image credit: SportSG)

Implementation Stage

Bukit Canberra's level of ecological restoration comprised several biodiversity enhancement strategies, including the conservation of existing habitats and areas of high biological integrity and enhancement of existing habitats by increasing the diversity of flora species to attract more fauna while recreating habitats. These were applied in the three habitat zones (Fig. 19).

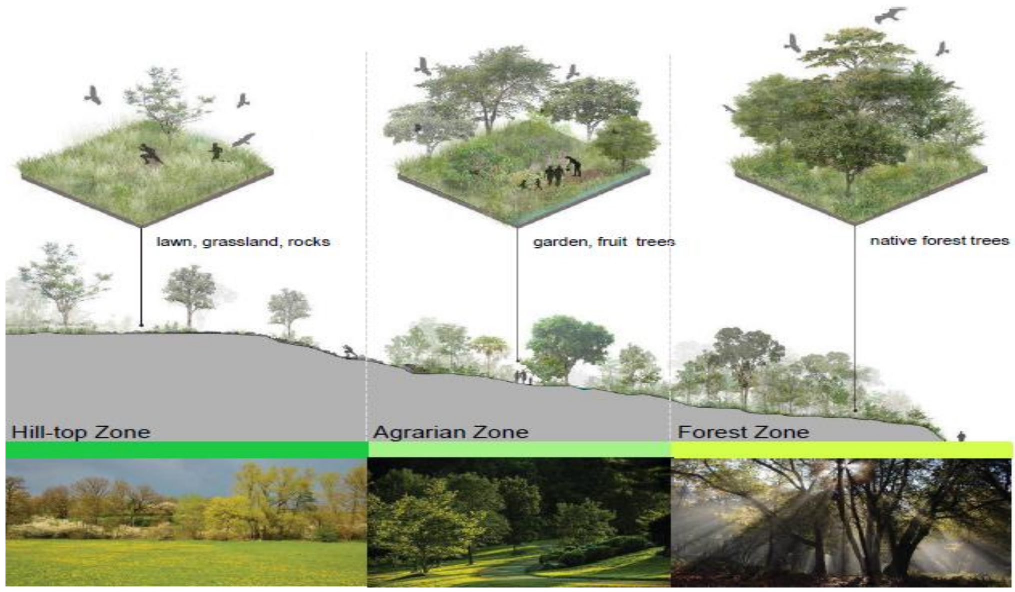


Fig. 19. This is an artist impression of the habitat types produced by the consultancy. (Image credit: SportSG)

The Forest Zone that had minimally 70% canopy coverage with high density trees was targeted to be ecologically linked to the surrounding nature ways in Sembawang while serving as the main refuge core for biodiversity and habitat creation. The Agrarian Zone would form a transitional landscape before the Hilltop Zone, where dense and multi-tiered planting of fruit trees and herbaceous shrubs contributed to a woodland habitat with 40–50% canopy coverage. At the Hilltop Zone, where most of the existing managed landscape were, significant trees such as Ficus were retained to allow for biodiversity hotspots to continue up the hilltop whilst bringing in more thematic yet naturalistic gardens to complement the English Arts & Crafts style of the Canberra House, through the use of native flora species.

Bukit Canberra's greenery plan encompasses a diverse and thematic comprehensive planting strategy (Fig. 20) that serves to simultaneously function as an attractive recreational and ecological landscape.

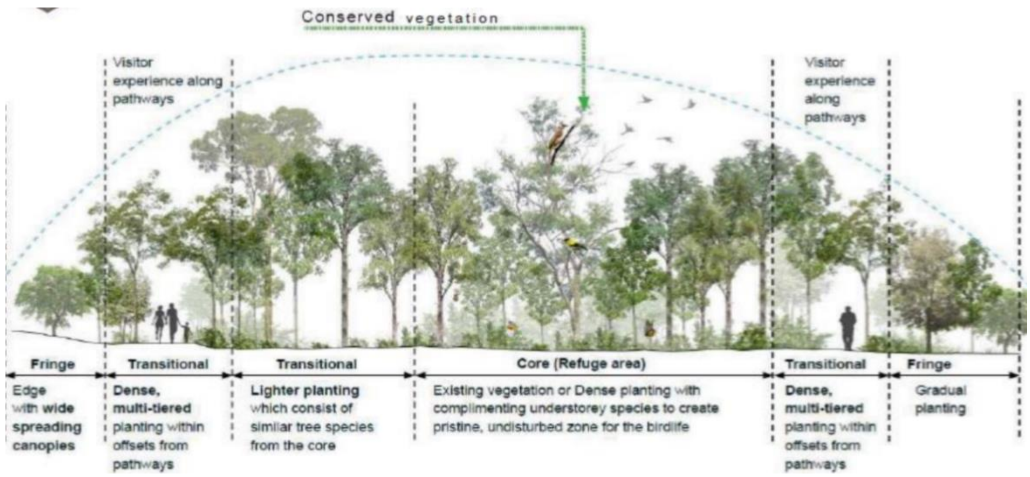


Fig. 20. This is an artist impression of the greenery plan encompassing a diverse and thematic planting stratetegy produced by the consultancy. (Image credit: SportSG)

Connectivity of users of all ages and abilities to the natural environment was ensured in three distinct areas, firstly, the Forest Gym, secondly, the Nature Playgarden and lastly, the Therapeutic Garden. These spaces drew inspiration from nature, providing users a healthier environment to interact in. In the Forest Gym, users would be able to do physical workout with equipment that were made of natural material such as recycled timber while being immersed in a dense forest-like environment. Similarly, in the Nature Playgarden, users of a young age would be introduced to a play environment that mimic the forest and natural environment. This would help to increase biophilia and facilitate connection with nature at a young age. The

Therapeutic Garden provides a platform for nursing homes and local community to have horticultural therapy where the interaction with flora helps to heal through a multi-sensorial experience.

Bukit Canberra contains a high percentage of built structures including a hawker centre and sports centre that seamlessly integrate into the landscaped hill that will be implemented progressively. This will be achieved through various vertical greenery such as green roofs, balcony greening and pocket gardens within the buildings. These help to cool the micro-climate, improve air quality and enhance aesthetics, among others.

Lastly, Bukit Canberra incorporates PUB's Active Beautiful and Clean water sensitive urban design typologies. Detention basin and vegetated swales are introduced as nature-based solutions for drainage systems while also serving as a platform to restore aquatic habitats. Through this habitat restoration, users will get to enjoy a fresh array of diverse planting along the riparian habitats, thus, increasing user interaction with these nature-based features during both flooded and non-flooded periods.

Programmatic Stage

To further strengthen Bukit Canberra as a community hub, various programmatic software will be incorporated and supported at an inter-agency level which includes Sports Singapore, Ministry of Health Singapore Holdings, National Environment Agency, National Heritage Board, People's Association and National Parks Board. Bukit Canberra's hardware is also programmed such that it encompasses an array of spaces for users of all ages and background that focuses on health, sport and fitness, education, history and many more. With cross-programming between agencies and various events using the integrated facilities designed within Bukit Canberra, the use of an integrated service counter for all programmes and events will help users to easily access links to various co-locating agencies and public services.

Bukit Canberra is also promoted as a lifestyle destination where music, arts, heritage trails and health and wellness sessions are all supported with activities and messages that aim to inculcate civic-mindedness within the community (Fig. 21). Additionally, volunteers will be rallied as Friends of Bukit Canberra, where they can be involved in leading the guided walks or tours, providing advice and guidance to tenants of Bukit Canberra on gardening within the childcare centre and elderly care centre.

Fig. 21. Artist impression of therapeutic garden in Bukit Canberra. (Image credit: SportSG)

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Annex A

Project name: ____

Project Lead:	
Project Coordinator:	
Specialists:	
Date:	Version:

Phase/Stage 1: **PLANNING**		Check	NA
Site Context Analysis			
1	Historical Maps - Identify key historical vegetation and waterways. - Highlight ecological connectivity to nature areas. - Historical maps of Singapore: https://libmaps.nus.edu.sg/ - NAS for old aerial images https://www.nas.gov.sg/	☐	
2	Connectivity: Park Connector Network (PCN) Masterplan Connectivity: Nature Ways	☐	☐
3	Surrounding Land-use: URA Masterplan - https://www.ura.gov.sg/maps/ - URA Parks and Waterbodies plan	☐	☐
4	Satellite image (latest): Parks Planning (PP)/MAVEN - MAVEN/Google	☐	☐
5	Topography: SLA Lidar and Topography Survey - Request from PP/Design SLA Lidar - Parks Development (PD) to conduct topographic survey	☐	☐
6	Roads: Plans to reflect LTA road kerb, Road Reserve layers, Road works and new roads. - Request from PP. - Refer to MAVEN, to seek rights from IT when necessary.	☐	☐
7	Surrounding Buildings: - Request from PP latest development in the development proximity. - Refer to MAVEN or OneMap for existing buildings - Information on Building height, footprint, design and use.	☐	☐

8	Drainage Reserve & Services: - Request from PP/Greenery & Development Planning (GDP) for drainage reserve layer/pipeline/sewer works/services (SP power, Singtel etc). - Refer to MAVEN, to seek rights from IT when necessary.	☐	☐
9	Vegetation Layer: - Request for vegetation map layer info rights on MAVEN from National Biodiversity Centre (NBC). - NUS satellite studies from NBC. - PD/Ops conduct tree (>1m girth) tagging survey and flora survey.	☐	☐
10	Biodiversity: - Request for significant biodiversity areas from NBC/BIOME. - NUS satellite studies from NBC. - PD/Ops conduct Biodiversity survey (identify transects, areas for camera trapping, stream surveys, water quality tests, soil data)	☐	☐
11	Heat Resilience: - Refer to heat resilience document - Hardscape to greenery ratio (3:7 ratio)	☐	☐
12	Flood Resilience: - Check whether the park is in the flood-risk area pertaining to sea level rise - Check whether park is within flood-prone areas – localised context	☐	☐
13	Sustainability - Understanding parks energy requirement - To identify goals for sustainable energy usage (BCA Zero energy buildings) - Identifying areas to locate solar panels/skylights/solar tubes - Identify amount of savings/cost recovery - Consider other sustainable sources of sustainable energy (Wind energy, waste to energy plant, kinetic energy, etc.) - Sustainable infrastructure and building materials (Mass Engineered Timber, Bamboo, reconstructed wood) - Food Sustainability (Edible gardens, allotment gardens, plant factory)	☐	☐

14	Smart Operations - Integrated Garden Management System - Smart Lighting - Mobile Application for Parks - Robotic video analysis - Automated Irrigation - CCTV and People-counting systems (face recognition, temperature screening) - Automated lawnmower - Visitor Service Smart Kiosk	☐	☐

Goals of Restoration: ***(tick one of the following goals for the project)***

Identify/Produce a plan on the habitat types that will be created/restored
***Habitat Types:*____________________________________**_(e.g., Grasslands/Wetlands)_

NATURAL: *The distinctiveness of a purely natural ecosystem that spans over a long undisturbed period from minimal interventions of man. (Untouched, Wild, Spontaneous)*
e.g., Primary and secondary forests: Rifle Range Nature Park

NOVEL: *Where ecosystems have been pushed beyond their historical range of variability. (Designed, Managed, Wild, Spontaneous)*
e.g., Regional parks with 'ecological' planting: Bidadari/Jurong Lake Gardens

HYBRID: *An ecosystem that is modified/compounded with curated landscapes. (Designed, Managed, Wild, Historical, Spontaneous)*
e.g., Nature parks, Parks at the forest edge: Pasir Ris Park

Phase/Stage 2: **IMPLEMENTATION**	**Check**	**NA**
Ecological Processes		
• Discuss based on information on processes such hydrology, edaphic (soil) conditions, topography, biodiversity baseline and ecological connectivity gathered at planning stage • Determine topographical, hydrological and landform changes necessary to achieve habitat goals		
1 Naturalise Waterways & Waterbodies **Vegetated swales, bio-retention ponds, flood plains and waterbodies**		
• To identify goals for increasing naturalised waterways	☐☐☐	☐
• Treatment of runoff of total site area through ABC design features (10%, 11–35%, >35%)	☐☐☐	☐
• To site naturalised drains at suitable location - Point of interest/attraction - Biodiversity corridor (connection to forest vegetation/vegetation patches) - Area with maximum visual porosity (less tree planting along naturalised streams) - Human interaction with stream	☐☐☐	☐
• To consider catchment and quality of water source - Topographic study - Water quality sampling - Identify the pollutants to remove	☐☐☐	☐
• To consider storm water management requirements - Function (collection pond/drainage) - Capacity of stream/rain garden - Level of inundation - Frequency of flood – Flood evacuation plan (if necessary)	☐☐☐	☐
• To identify opportunities for rainwater harvesting (Irrigation)	☐☐☐	☐
• To restore/create habitats - Identify habitat goals/species recovery goals - Stream habitat/fish habitats/dragonfly habitat/butterfly attracting planting - Planting along streams to encourage biodiversity roosting along streams	☐	☐

Resources:

- Naturalising existing blue infrastructure
- Design guidelines and toolkit for naturalised waterways and waterbodies

Naturalise coastal waterfront

- Identify historical stream connection to sea and goals for naturalising (25%/50%/100%) ☐ ☐
- To site naturalised waterfront/intertidal stream at suitable location ☐ ☐
  - Point of interest/attraction
  - Biodiversity corridor (connection to forest vegetation/vegetation patches)
  - Human interaction/experience
- To consider catchment and quality of water source ☐ ☐
  - Topographical study
  - Water quality sampling
  - Identify the pollutants to remove
- To consider coastal erosion impacts ☐ ☐
  - Conduct Coastal erosion and deposition study
  - Optimising coastal protection measures with habitat creation substrate
- To restore/create habitats ☐ ☐
  - Conduct biodiversity baseline studies along existing coast
  - Identify habitat goals/species recovery goals
  - Degree of daily inundation
  - Planting/structures along streams to encourage biodiversity roosting along streams

	Habitat Restoration	CHECK	NA
2	Conserve more Native Plants & Animal Species		
	Add in the characteristics		
	Vegetation structure		
	• To identify goals for native vegetation conservation (e.g., large trees (>1m girth))	☐	☐
	• To identify goals for native vegetation enhancement/rehabilitation (25%/50%/100%)	☐	☐
	• Study existing greenery/habitats within and abutting park and plan new zones of habitat improvement/intervention (e.g. new back mangrove buffer zone around mangrove core, new coastal forest areas, new freshwater swamp belt integrated with Nature Way)	☐	☐
	• Plan vegetation structure along both horizontal and vertical planes. Habitat heterogeneity along each plane is key to allow for diversity of ecological niches.	☐	☐
	- (Horizontal:) Establish a Habitat Mix Plan within park (e.g., freshwater swamp, grassland, woodlands)	☐	☐
	- (Vertical:) Create the different levels within a rainforest structure (e.g., ground, shrub, subcanopy, canopy and emergent layers)	☐	☐
	Plant Selection		
	• To identify goals for retaining existing site floristics (25%/50%/100%)	☐	☐
	• Plan floristic assemblage of each habitat zone based on habitat restoration goals, e.g., use of native species found in specific habitats vs use of exotics at hybrid or novel landscapes (e.g., Jurong Lake Gardens Grasslands)	☐	☐
	• Create planting plans based on palettes for each habitat type	☐	☐
	• Curate unique native plant collections (discussion with specialist)	☐	☐
	Conservation of Biodiversity		
	• Identify goals of biodiversity conservation (species, habitat)	☐	☐
	• Identify goals of habitat creation and biodiversity connectivity (species, habitat and compatibility to park programmes)	☐	☐

• Integrate with network of green spaces that function as ecological corridors (i.e., nature way, PCN)	☐	☐
• Enhance habitats that harbour biodiversity and provide conduits for movement between nature areas	☐	☐
• Consider infrastructure to aid fauna connectivity (rope bridges, culverts) and habitat creation (habitat boxes, bee hotels)	☐	☐
• Enrich existing habitats to support Species Recovery Programme (consult specialists)	☐	☐
• Study measures to reduce potential human wildlife conflict (if any).	☐	☐

Resources:

- Plant palette templates by habitat types
- Green spaces designated as collections
- Species Recovery/Re-introduction List
- Introducing fauna design guidelines

Ecological Aesthetics		CHECK	NA
3	Curate more Natural Habitats/Vegetation		
	Non-manicured landscapes		
	• Mimics tropical forest structure	☐	☐
	• Randomised planting in clusters and groves	☐	☐
	Multi-tiered planting		
	• Mix of small, medium & large trees with understorey plants	☐	☐
	Plant diversity		
	• Diversity of plant species showcasing foliage colours and textures	☐	☐
	• Integrating and extending nature ways into parks	☐	☐
	• Consideration for native and exotic species	☐	☐
	• Shade provision	☐	☐
	Sustainable landscapes & ecosystems		
	• Bringing back historical vegetation and habitat	☐	☐
	• Plants, planting and care regime to suit site context and landscaping themes	☐	☐
	Resources:		
	- Naturalistic landscape design guide		
	- Naturalistic landscape maintenance guide		

Phase/Stage 3: **PROGRAMMATIC (Hardware)**			Check	NA
Therapeutic Landscapes				
1	-	Design guidelines for Therapeutic Gardens (TG) in Singapore	☐	☐
	-	Grow the TG network	☐	☐
		New TG typologies		
Nature Playgardens				
2	-	Nature playgarden design guidelines	☐	☐
	-	Strategy plan for nature play in Singapore	☐	☐
	-	Courses for NParks and external audiences	☐	☐
Skyrise Greenery				
3	-	Raise industry's standard and increase outreach	☐	☐
	-	Skyrise naturalistic planting	☐	☐
	-	Pilot projects/showcase projects	☐	☐
Biophilic Designs				
4	-	Design guideline for developers to provide additional setback for certain areas for ecological/green connectivity	☐	☐

Phase/Stage 3: **PROGRAMMATIC (Software)**		Check	NA
1	**Community in Bloom:** A nationwide, ground up gardening movement that aims to foster a community spirit and bring together residents, both young and old, to make Singapore our garden.	☐	☐
2	**Community in Nature:** Encourage stewardship of nature amongst Singaporeans through organized research endeavours plus collecting information that will inform conservation management strategies.	☐	☐
3	**Friends of The Park (FoTP):** Ground-led initiative to promote stewardship through active stakeholders and volunteers from diverse backgrounds.	☐	☐
4	**FoTP:** Citizen Parks Engagement: involve communities in the design, development and management of our parks and green spaces.	☐	☐
5	**One Million Trees Movement:** Aims to redouble Singapore's efforts to green its urban infrastructure on an unprecedented scale, to achieve the vision of making a City in Nature.	☐	☐
6	**Gardening with Edibles:** Brings nature into homes, where the community plays a key role in the ownership and stewardship for nature which will bring forth benefits of health and well-being.	☐	☐
7	Education and Volunteer programmes	☐	☐
8	Youth@SG Nature	☐	☐

CHAPTER 26

Reef Restoration in Singapore

Chou Loke Ming

The loss of more than half of Singapore's coral reef habitats to land reclamation and exposure of the remaining reefs to chronic sedimentation necessitate active restoration interventions. Singapore's reef restoration activities stretch back to the late 1980s. Two initiatives dealt with artificial reefs involving large and heavy structures that required barges and cranes to transport and deploy. The majority dealt with restoration techniques that could be handled by scuba-diving researchers. The earlier artificial reef project in 1989 deployed structures made from tyre pyramids and hollow concrete frames. The project was carried out by the National University of Singapore and supported under the ASEAN-USAID Coastal Resources Management Project. The scale of this artificial reef was dwarfed by the more recent artificial reef project (Singapore's largest artificial reef structures) in 2018 where 10-metre-tall purpose-built concrete and fibreglass structures were placed at Sisters' Islands Marine Park (See Chapter 14). This project was a collaboration between JTC Corporation (JTC) and National Parks Board (NParks).

The large majority of reef restoration projects dealt with coral translocation and strategies to enhance survival and growth of corals, and where structures were involved, they were small and portable. Collectively, the research has revealed much information valuable to the advancement of reef restoration in Singapore's marine environment. This would not have been possible without the funding support from and/or collaboration with various agencies, such as Keppel Group, Housing and Development Board, JTC, Maritime and Port Authority, National Environment Agency, NParks, National Research Foundation (Marine Science Research and Development Programme), Sentosa Development Corporation, Singapore Maritime Institute, Singapore Tourism Board, Wildlife Reserves Singapore Conservation Fund, and the European Union.

Reef restoration efforts employing techniques that overcome sedimentation challenges have indicated their viability (Ng *et al*., 2016a; Chou *et al*., 2018). These range from the provision of sloping solid substrata (Low *et al*., 2006) or horizontal mesh surfaces that prevent sediment accumulation (Ng & Chou, 2014). This will complement the observed natural coral colonisation of seawalls (Chou *et al*., 2010; Ng *et al*., 2012) and other human-made structures such as jetty pilings (Chou & Lim, 1986; Ong & Tan, 2012) lining the urban coast.

In-situ coral nurseries have a significant role in reef restoration efforts in a sediment-stressed environment. Studies on two scleractinian species, *Pachyseris speciosa* and *Pocillopora acuta* (Poquita-Du *et al.*, 2017) indicated that fragments raised in nurseries for five months before being transplanted to the reef substrate, grew significantly faster by three to five times compared to those that were transplanted directly without a nursery phase (Afiq-Rosli *et al.*, 2017). The faster growth of transplants in nurseries augmented their size and continued to manifest after final transplantation to the reef, enabling them to perform better than directly transplanted fragments.

Nurseries can also be used to nurture 'corals of opportunity' (COPs), which are naturally fragmented corals lying free on the reef floor or coral juveniles that have recruited on loose rubble. COPs raised in nurseries at Pulau Semakau (Chou *et al.*, 2009) and nubbins (small fragments) raised in nurseries at St John's and Lazarus Islands (Bongiorni *et al.*, 2011) showed that improved survivorship and growth rate can be achieved in Singapore's sediment-impacted waters. These studies highlight the feasibility of establishing coral nurseries in other locations to preserve scleractinian genotypes from reefs that will be directly affected by coastal development.

The coral nurseries themselves served as microhabitats to enhance biodiversity despite the sedimentation, attracting a large variety of species such as fishes (Taira *et al.*, 2016) and reef-associated invertebrates (Wee *et al.*, 2019). These nurseries also provided opportunities for recruitment, settlement, and development of reef fauna. They enhance ecosystem functioning in degraded as well as non-reefal sites while nurturing coral fragments for transplantation (Chou *et al.*, 2018).

It is important to consider preserving the locality's genetic diversity when transplanting corals from a source reef about to be exposed to development impact. Investigations of four coral species from such a reef showed that 33% to 40% of colonies can represent 80% of genetic diversity and more than 50% of colonies represent more than 90% of genetic diversity (Afiq-Rosli *et al.*, 2019). Hence, not all colonies need to be relocated when resources are constrained. Colonies of hermaphroditic species can be collected from over a smaller area, while gonochoric species can be collected over a larger spatial area, the latter having greater genetic variability over larger distances.

Biodiversity on artificial substrates developed through natural colonisation can be enhanced by active transplantation particularly in the intertidal zone. Natural colonisation showed the viability of hard structures such as seawalls as habitats for biological communities (Ng *et al.*, 2015) and active transplantation can further enhance the structure's ecological value. Fragments of five species of scleractinian corals, three species of soft corals and three species of sponges reared in *ex-situ* nurseries prior to transplantation exhibited variable survivorship and growth. The scleractinian coral *Porites lobata*, soft coral *Lobophytum* sp., and sponge *Lendenfeldia chondrodes* had high survivorship, rapid growth and extended mean survival times two years after transplantation. Coral species with massive or encrusting growth forms were best at establishing and developing on seawalls and observed to provide shelter and food for reef fish and gastropods.

Active restoration can help to increase the intertidal biodiversity of seawalls but must take into account that not all species can survive conditions at seawalls, particularly those with an early developing pioneering but competitive community. Similarly, not all species do well when transplanted to subtidal seawalls. Of six species investigated, *Hydnophora rigida*, *Podabacia crustacea*, *Echinopora lamellosa* and *Platygyra sinensis* had sustained growth and survival rates exceeding 90% after six months (Toh *et al.*, 2017). The study also showed how involvement of volunteers could lower the labour cost of the transplantation effort. In a recent transplantation project from 2013 to 2019, 904 coral fragments were transplanted to cover 150 square metres of degraded reef and create 272 square metres of 'new' reefs (Chou *et al.*, 2016). The 'new' reefs are non-reefal areas on which coral transplantation was attempted to determine if reef communities could be generated.

Many restoration initiatives are supported by short-term projects over durations that do not allow for long-term assessment. Sessile lifeform diversity developed from natural recruitment on fibreglass reef enhancement units (Ng *et al.*, 2016b) increased significantly over a span of 10 years with hard corals and coralline algae contributing most to the temporal dissimilarity. The reef units augmented ecosystem functioning with 119 sessile and mobile taxa utilising them for food and shelter. It must be emphasised that long-term monitoring is essential for assessing the effectiveness of reef restoration efforts (Chou *et al.*, 2016).

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CHAPTER 27

Future Directions of Habitat Restoration and Enhancement in Singapore

Lena Chan & Lim Liang Jim

The Story So Far

This Handbook on Habitat Restoration showcases only 24 diverse habitat restoration initiatives, spread across the whole of Singapore (Fig. 1 & 2), out of the many other past and ongoing habitat restoration and enhancement work that the National Parks Board (NParks) has had implemented. From an ecological perspective, the ecosystems that are restored or enhanced cover a broad spectrum that are found in Singapore, including forests, freshwater swamps, rivers, wetlands, freshwater marshes, grasslands, coastal forests, beach vegetation, urban ecosystems and coral reefs. As a result, these habitat restoration and enhancement efforts contribute significantly to the conservation of Singapore's native biodiversity.

Fig. 1. The above map shows the locations of the habitat restoration initiatives carried out across Singapore. (Image modified from OneMap)

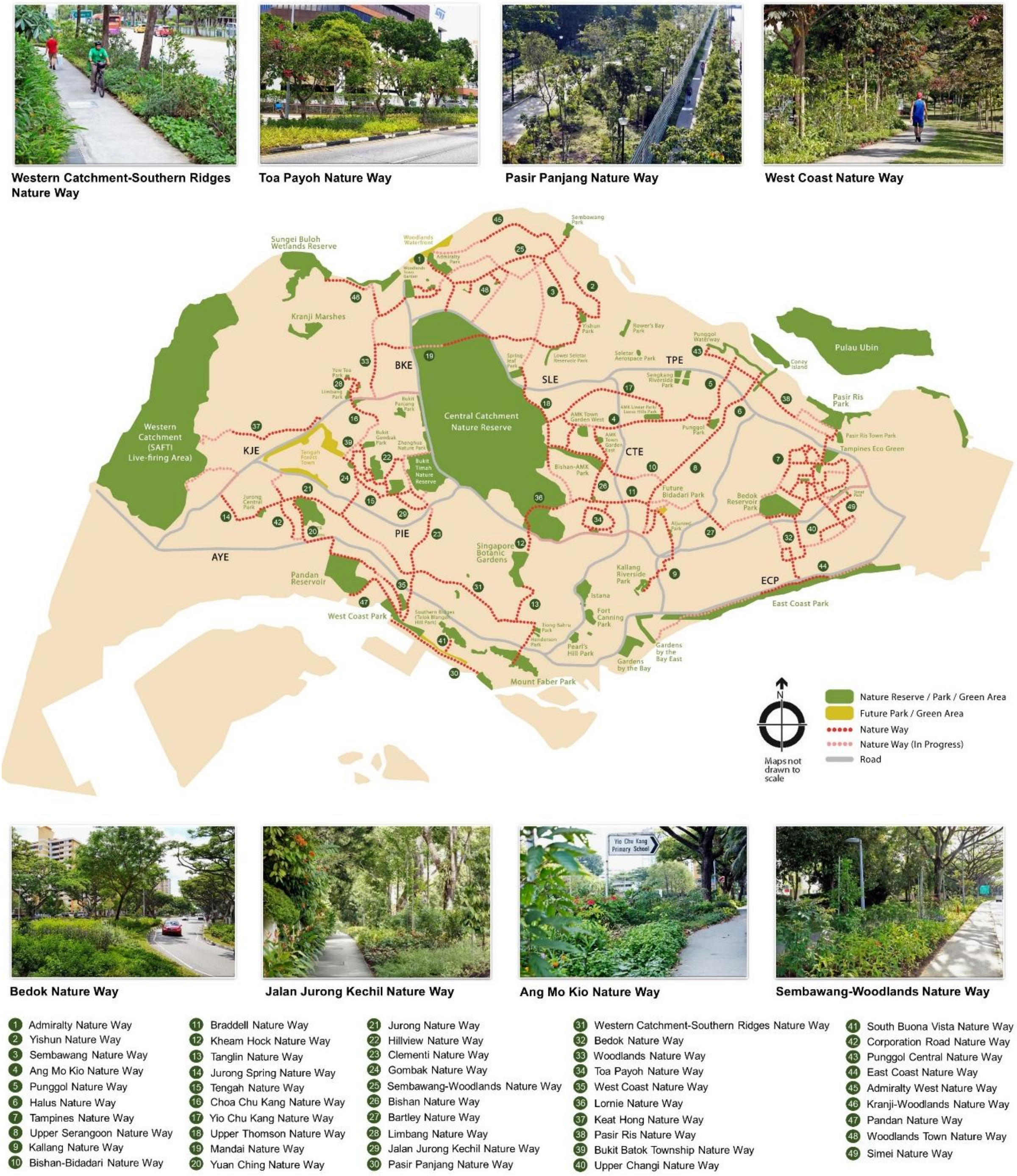

Fig. 2. The current extent of the nature ways is presented in the above map.

Central to making Singapore a City in Nature a reality is the conservation and restoration of ecosystems. This linkage is discussed in Chapter 1. Playing our part as a global citizen in biodiversity conservation, the publication of this handbook is NParks' contribution to help build capacity in making the UN Decade on Ecosystem Restoration 2021–2030 a success.

The handbook has a chapter on general principles and approaches that are frequently used and well-tested locally and globally (Chapter 2) for easy access by practitioners of habitat restoration and enhancement.

To ensure credibility and consistency in the habitat restoration initiatives, the scientific approach of systematically identifying targets, setting goals and objectives, selecting appropriate methodologies and monitoring indicators was adhered to as closely as practical. The methods used for habitat restoration were diverse, including natural or assisted natural regeneration, framework species, and maximum diversity method, and a combination of methods. Emphasis was placed on engaging the community and enhancing park-users' experience as it was recognized that social resilience was key to long-term sustainability of these efforts.

Additionally, it is crucial that the health status of the ecosystems be monitored regularly, and expeditious adaptive management measures be applied to retain the integrity of the whole system.

There are far more NParks' officers, partners and collaborators who contributed to making the habitat restoration and enhancement projects featured in this handbook a successful reality than the 55 listed authors. From a strategic perspective, the involvement of officers from at least fifteen NParks' divisions and external agencies attests to the inter-disciplinary and cross-sectoral nature of the projects.

NParks' officers have a wealth of knowledge and experience in botany, horticulture, zoology, planning, and biophilic design. From a technical perspective, the officers applied their skills and knowledge in the implementation of the restoration projects innovatively. Most of the case-studies contained lists of plants that were used for restoration and enhancement for different habitat types and for varied purposes as in the Learning Forest (Chapter 3), Rifle Range Nature Park (Chapter 5), Coney Island Park (Chapter 11), Kent Ridge Park (Chapter 15), and the HortPark Bee Trail (Chapter 17). Checklists of bird, dragonflies and damselflies, butterflies and moths, and bees and wasps that were recorded a few years after the completion of the Bishan-Ang Mo Kio Park (Chapter 9) were shared. For keen ornithologists, Kranji Marshes (Chapter 10) and Hampstead Wetlands Park (Chapter 19) had good reference lists of birds found in these two habitat restoration sites.

Restoration efforts commenced in some areas like the Learning Forest (Chapter 3), Eco-Link@BKE (Chapter 8), river restoration at Bishan-Ang Mo Kio Park (Chapter 9), mangrove restoration at Pasir Ris Park (Chapter 21), etc., more than 10 years ago. These sites continue to thrive and render multiple free ecosystem services like cooling the ambient temperatures, reducing flooding, retaining moisture during drought conditions, providing habitats for wildlife, serving recreational and educational opportunities, and many more. That people and biodiversity are still benefiting is an indication of the value of restoration and rehabilitation.

Positive outcomes of more recent projects like an increase in the quality and quantity of biodiversity recorded, are already evident in Kranji Marshes (Chapter 10), Kent Ridge slope stabilisation site (Chapter 15), parks in one-north (Chapter 16), Hampstead Wetlands Park (Chapter 19), etc. It could be inferred that results from restoration could be achieved rapidly.

Way Forward and Future Directions

It is crucial for cities in particular, that we should invest in more habitat restoration so that ecological resilience and resilience against the consequences of climate change could be addressed together more effectively and synergistically. It has been shown that the benefits of restoring a diversity of ecosystems in urban areas are ecologically and socially desirable as well as economically advantageous (Elmqvist *et al.*, 2015). As environmental changes accelerate (Prober *et al.*, 2019), and become more complex and unpredictable, it is imperative that there be a paradigm shift in our approaches to habitat restoration. It is no longer sufficient to restore or rehabilitate to the former ecological state, but the following will also have to be taken into consideration:

1) There is a diversity of reasons for habitat restoration, some of them might be conflicting and hence, practitioners have to set and balance priorities. For example, not all climate change solutions are good for biodiversity, but most biodiversity conservation actions usually contribute positively to mitigate negative climate change effects.
2) A broad range of ecosystems must be restored, i.e., quality not merely quantity. Hence, it is important to draw a plan to coordinate a range of habitat restoration projects that would be diverse in nature. This would increase ecological resilience, agility and flexibility in the event of scenarios of extreme conditions and unpredictability.

3) It is essential to include a complete representation of all the successional stages rather than concentrate on the climax stages. This strategy also helps to increase ecological resilience, agility and flexibility as well as long-term self-sustenance.
4) Long-term monitoring and adaptive management must be mandatory.
5) The involvement of all sectors of the community is pivotal to the success of the initiatives. Since it is difficult to predict the future, it is, hence, crucial to plan for known unknowns or unknown unknowns.

Final words

The Handbook on Habitat Restoration is a work that distils the best of NParks' passion, technical expertise, and dedication to collaboration with numerous partners. It is a celebration of the past habitation projects that we had carried out; the ones which are still being implemented at present; and many more that we will be embarking on in the future. We have learnt much during this journey and will continue to innovate, improve, improvise, adapt, change, and renovate for biodiversity conservation and resilience to climate change.

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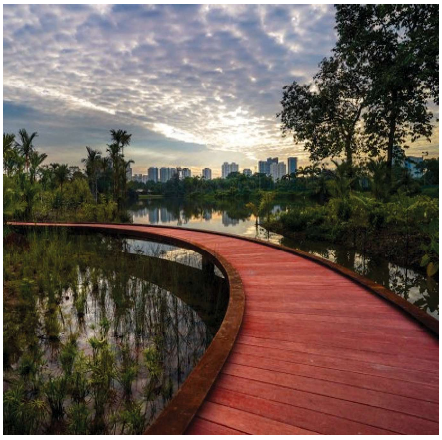

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