CHAPTER 2
Principles and Approaches to Habitat Restoration and Enhancement with Particular Reference to the Singapore Context

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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.

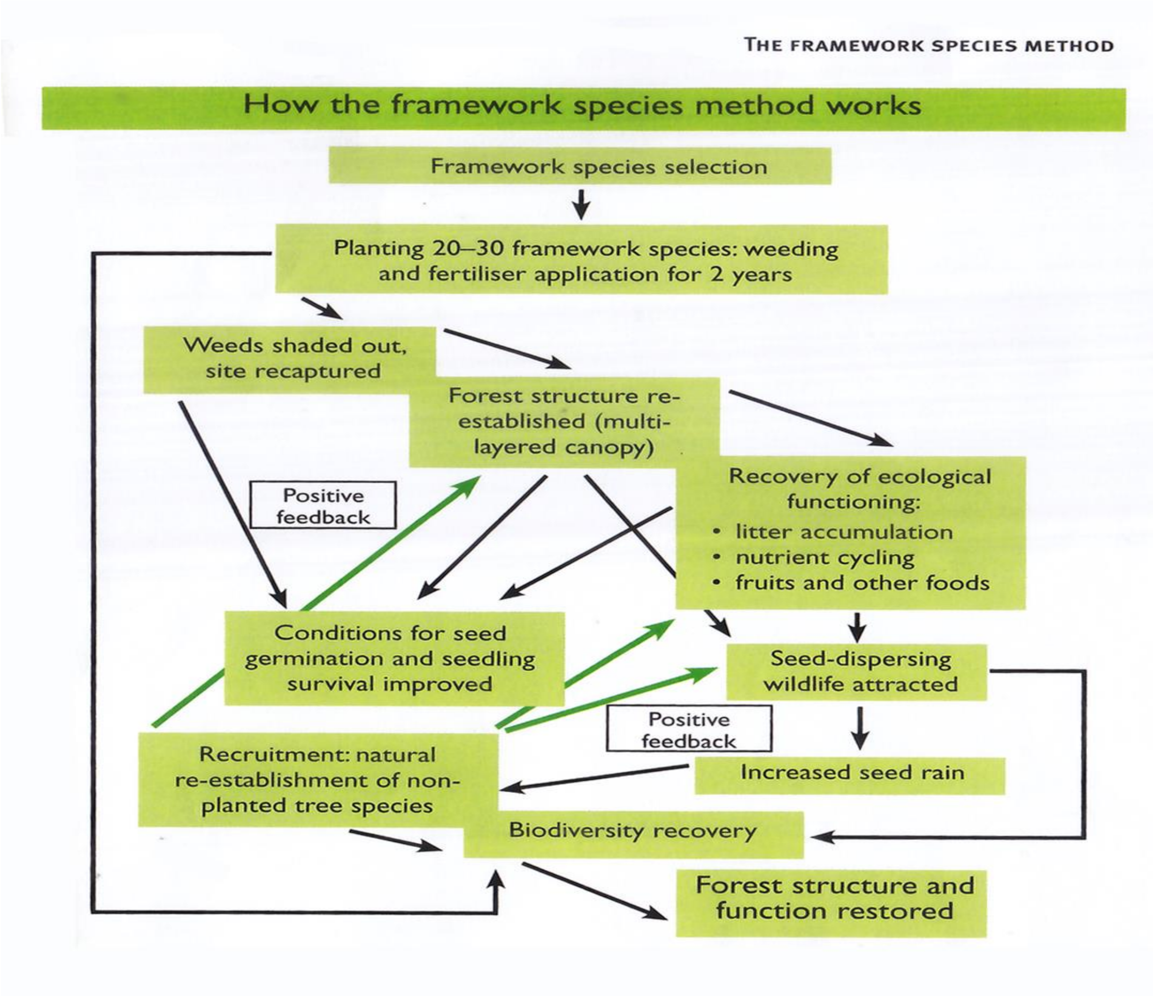

Fig. 3. Processes of the framework species method. (Source: Elliott *et al.*, 2019)

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.

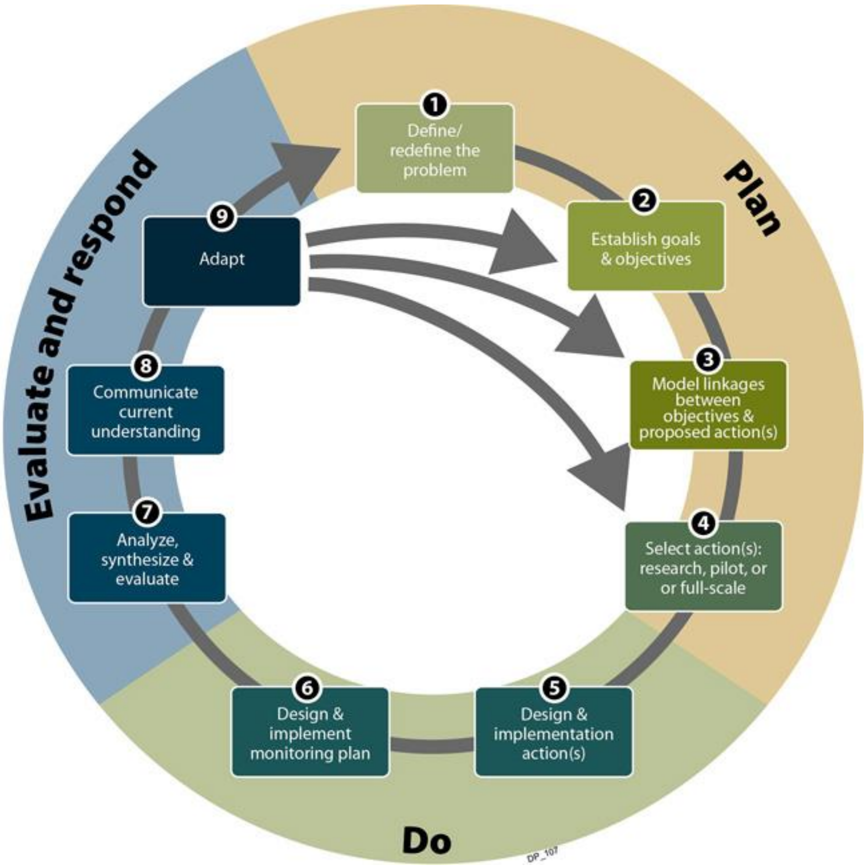

Fig. 4. Nine-stage framework for adaptive management. (Source: Wiens *et al.*, 2017)

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.

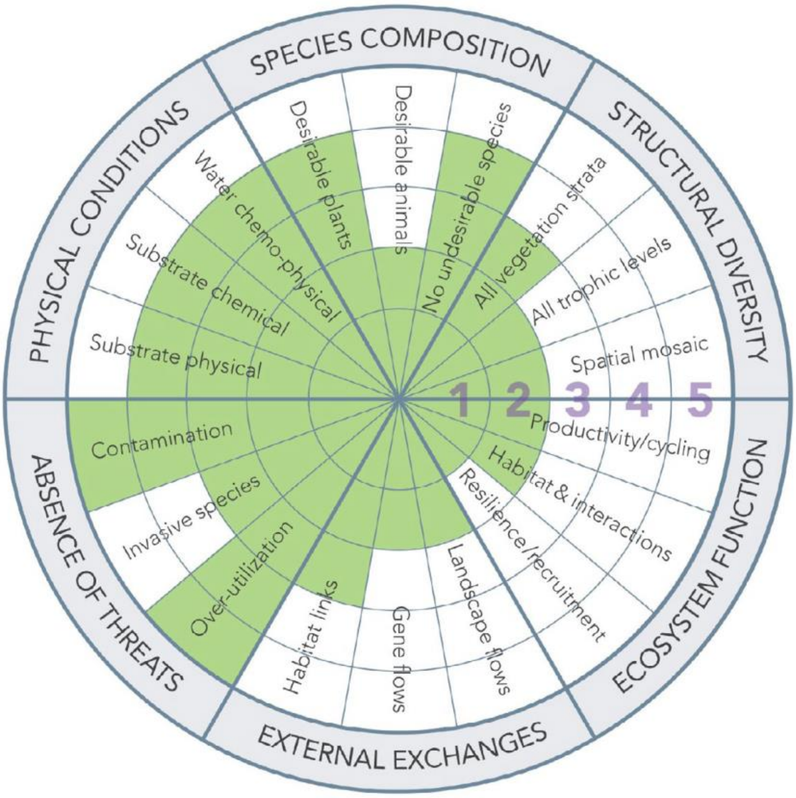

Fig. 5. A sample "recovery wheel" where the project manager for a habitat restoration effort can illustrate progressive stages of improvement in the restored ecosystem. (Source: Macdonald *et al.*, 2016)

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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