CHAPTER 13
Coastal Protection Synergy with Mangrove Restoration in Pulau Tekong

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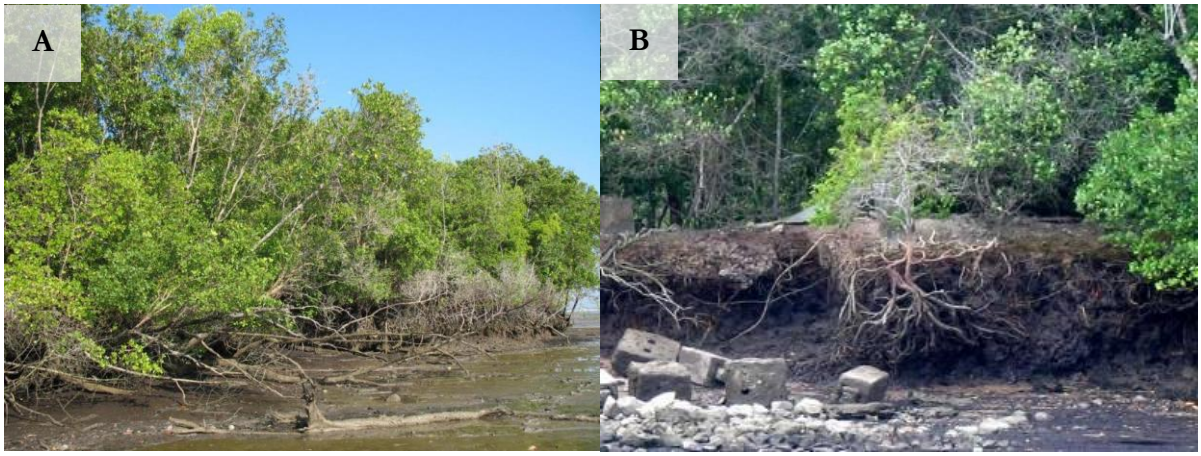
Introduction

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

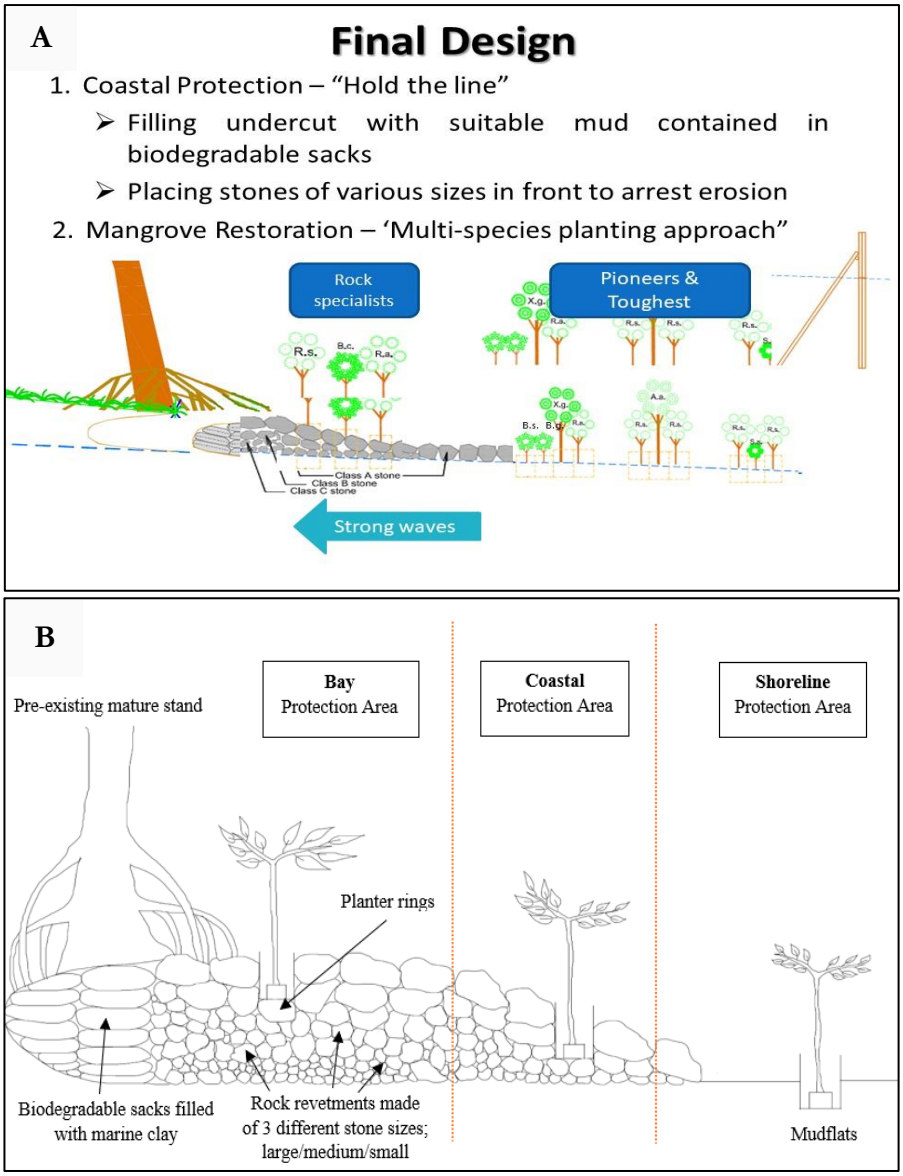
The initial design intent was to plant mangroves throughout to provide a natural protection along the entire coastline. To ensure that the solution fits the local environment, we conducted literature surveys, baseline hydraulic modelling studies, and a pilot field trial to test three things, i.e., (1) 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.

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