هيئة البيئة - أبوظبي
Environment Agency - ABU DHABI

مبادرة القرم أبوظبي
Abu Dhabi Mangrove Initiative

In partnership with:

Emirates Nature WWF

UNITED ARAB EMIRATES
MINISTRY OF CLIMATE CHANGE
& ENVIRONMENT

Mangrove Restoration Guidelines for the United Arab Emirates

All maps are not an authority on international or inter-emirates' boundaries.

Mangrove Restoration Guidelines for the United Arab Emirates

UNITED ARAB EMIRATES
MINISTRY OF CLIMATE CHANGE
& ENVIRONMENT

About the Ministry of Climate Change and Environment

The Ministry of Climate Change and Environment (MOCCAE) was established in February 2006 as the Ministry of Environment and Water. In February 2016, its name was changed as part of a ministerial reorganisation prompted by the inclusion of the climate change portfolio into its existing mandate. The ministry leads the UAE's efforts in confronting climate change and attaining the objectives outlined in the Third Update of the Second Nationally Determined Contribution for the UAE. These objectives encompass a 40% reduction in emissions by 2030, following the projected business-as-usual trajectory, and the achievement of The UAE Net Zero by 2050 strategic initiative through collaboration with relevant entities.

The ministry's vision is to achieve sustainable food and environmental security. It adopts a climate-neutral approach to protect and develop environmental systems and enhance food and water security for sustainable development. The ministry translates this through efforts to reduce emissions across all sectors in the UAE, invest in agriculture and sustainable food system development, advance environmental health programmes, preserve biodiversity, and maximise the benefits of ecosystem services.

For further details, please contact us on: info@moccae.gov.ae

هـيـئـة البيئـة - أبـوظـبـي
Environment Agency - ABU DHABI

About Environment Agency – Abu Dhabi (EAD)

Established in 1996, the Environment Agency – Abu Dhabi (EAD) is committed to protecting and enhancing air quality, groundwater as well as the biodiversity of our desert and marine ecosystem. By partnering with other government entities, the private sector, NGOs and global environmental agencies, we embrace international best practice, innovation and hard work to institute effective policy measures. We seek to raise environmental awareness, facilitate sustainable development and ensure environmental issues remain one of the top priorities of our national agenda.

About Emirates Nature-WWF

Environmental charity Emirates Nature-WWF leads the successful implementation of two multi-stakeholder Nature-based Solutions (NbS) projects in the UAE.

The flagship Nature-based Solutions (NbS) for Climate, Biodiversity & People project in the UAE project focuses on the holistic protection, restoration and management of Blue Carbon coastal ecosystems, including mangroves, seagrasses, and saltmarshes, to unlock multiple benefits for climate, biodiversity and people. With funding from HSBC Bank Middle East, as part of the Climate Solutions Partnership that aims to advance innovative nature and climate solutions, the project is a partnership between the Ministry of Climate Change and Environment (MOCCAE), the Minister of Economy (MoE), the Environment Agency – Abu Dhabi (EAD), the Government of Umm Al Quwain, Emirates Nature-WWF and the International Center for Biosaline Agriculture (ICBA).

Emirates Nature-WWF is also part of the Priceless Planet Coalition (PPC), the international initiative launched by Mastercard to restore 100 million trees globally. As the local implementation partner, Emirates Nature-WWF leads the restoration of mangroves in the UAE with the support of the Government of Umm Al Quwain, Ajman Municipality, and the Environment and Protected Areas Authority (EPAA) of Sharjah.

Content

List of figures

List of tables

Foreword

> Conservation, restoration, and planting of mangroves are complex processes and require scientific strategies and methodology, making it imperative to have a set of technical guidelines as reference. Which is the reason why these guidelines are so critical. They will support the UAE's commitment to boost its mangrove cover and allow different stakeholders to contribute to the cause in a planned and sustainable way.

H.E. DR AMNA BINT ABDULLAH AL DAHAK
Minister of Climate Change and Environment

I am pleased to present the 'Mangrove Restoration Guidelines for the United Arab Emirates'. A culmination of the efforts of the Ministry of Climate Change and Environment, the Environment Agency Abu Dhabi and Emirates-Nature -WWF, this publication reflects the dedication of these entities to fostering thriving mangrove ecosystems in the UAE. Based on global best practices and scientific research, this publication offers guidelines to undertake successful mangrove restoration projects in the UAE and identifies ways to maximise the economic, social and environment benefits of mangroves.

Mangroves are a vital component of coastal and marine biodiversity, offering a critical nature-based solution for climate action. Mangroves not only play a critical role in protecting marine ecosystems but also act as natural carbon sinks, making them integral to the UAE's Net Zero 2050 Strategy. The dense coastal forests of mangroves store carbon up to 400 percent faster than land-based tropical rainforests. They also provide breeding grounds for marine biodiversity and 80% of global fish populations depend on healthy mangrove ecosystems.

Acknowledging the importance of mangroves, the UAE embarked on a plan to plant 100 million mangroves across the UAE by 2030. The plan was announced at COP26, and the following year at COP27, the nation further cemented its commitment to mangroves by launching the Mangrove Alliance for Climate (MAC) in partnership with Indonesia. The aim of the alliance was to scale up, accelerate conservation, restoration, and plantation efforts of mangrove ecosystems for the benefit of communities within the UAE as well as around the world.

In May this year, the groundbreaking ceremony of the Mohamed bin Zayed-Joko Widodo International Mangrove Research Centre took place in Bali. Once ready, the centre will conduct further research in cultivating mangroves, enhancing their role as natural carbon sinks and in boosting nature-based solutions for climate action. Research will be conducted to improve coastal habitats and to promote biodiversity. The centre will also foster an exchange of knowledge in developing mangroves with different countries to compensate for the global loss of this valuable species.

Conservation, restoration, and planting of mangroves are complex processes and require scientific strategies and methodology, making it imperative to have a set of technical guidelines as reference. Which is the reason why these guidelines are so critical. They will support the UAE's commitment to boost its mangrove cover and allow different stakeholders to contribute to the cause in a planned and sustainable way.

Complete with data, insight and information, these guidelines ensure efficiency, cost-effectiveness, and environmental soundness of mangrove restoration projects with the aim of ensuring successful restoration outcomes that do not interfere with existing natural habitats or negatively impact existing mangroves.

These guidelines are a valuable tool for government entities, non-governmental organisations, community groups, corporations and investors seeking to undertake directly or fund mangrove restoration programmes in the UAE. I thank all our partners for their cooperation in the preparation of this document and urge communities and organisations to follow these guidelines to boost the mangroves of the UAE and contribute to our leadership's vision for achieving the UAE's sustainability goals.

Foreword

> Mangrove forests are unique because they serve as nature-based solutions (NBS) against the profoundly negative effects of climate change. This is due to their carbon sequestration abilities, which is particularly significant given the challenges of reducing greenhouse gas emissions and rising global temperatures.

H.E. DR SHAIKHA SALEM AL DHAHERI
Secretary General
Environment Agency - Abu Dhabi

Mangrove restoration is not new to the UAE or the Emirate of Abu Dhabi. The UAE's current mangrove conservation and restoration expertise is a legacy of the pioneering efforts made by the late Sheikh Zayed bin Sultan Al Nahyan, the nation's Founding Father.

His passion for marine and coastal environments saw the first mangrove plantation project initiated in 1966 along Abu Dhabi's coast – a clear demonstration of his vision and commitment to ecological preservation, establishing him as a key figure in the region's environmental movement, and a leader who was very much ahead of his time.

After the efforts to preserve and enhance Abu Dhabi's mangroves began, the Emirate of Abu Dhabi became one of the world's leading hubs for research, conservation and the rehabilitation of these precious ecosystems.

Mangrove forests are unique because they serve as Nature-based Solutions (NbS) against the profoundly negative effects of climate change. This is due to their carbon sequestration abilities, which is particularly significant given the challenges of reducing greenhouse gas emissions and rising global temperatures.

In February 2022, the Environment Agency – Abu Dhabi (EAD) launched the Abu Dhabi Mangrove Initiative (ADMI) during HRH Prince William, the Prince of Wales and Duke of Cambridge's, landmark visit to the UAE where, at Jubail Mangrove Park, he met His Highness Sheikh Khaled bin Mohamed bin Zayed Al Nahyan, Crown Prince of Abu Dhabi and Chairman of Abu Dhabi Executive Office.

Since the launch of ADMI in 2022, significant progress has been achieved in mangrove restoration in Abu Dhabi, with the launch of a partnership programme to bring together all partners contributing to restoration under one umbrella, and guiding these efforts to ensure success, thanks to the implementation of best practices, such as pre-restoration site suitability assessments and post-restoration monitoring.

Together with our partners, we have pioneered the use of cutting-edge technology in our mangrove planting efforts – namely, drones – which has enabled us to reach remote restoration sites, save time, reduce costs and invest more resources in pre-restoration and post-restoration monitoring. With more time and resources dedicated to pre and post-restoration monitoring, this has helped advance our scientific knowledge on the most effective mangrove restoration practices.

ADMI's goals also include implementing science-based restoration, prioritising protection, and working towards no net loss of any natural critical habitat, including mangroves. In our dedication to science-based restoration, we have established procedures requiring that all mangrove restoration efforts in Abu Dhabi be adequately planned and monitored.

To support efforts at a national level, we have collaborated with our key partners – the UAE Ministry of Climate Change and Environment, and Emirates Nature-WWF – to develop the following Mangrove Restoration Guideline for the UAE. A comprehensive and detailed national practice guideline for mangrove restoration, it is the first time this specific guidance tailored to the local context has been published.

The guideline aims to bring together in one document the expertise and knowledge established in the UAE. Furthermore, through many years of mangrove restoration in the emirate of Abu Dhabi, led by us at EAD, we hope that these guidelines will enable everyone in the UAE and wider region involved in mangrove restoration to benefit from our recommendations that are aligned with global best practices. It will also help all our stakeholders benefit from the innovations applied in the UAE, and Abu Dhabi Emirate specifically, regarding the application of technology to enhance restoration efforts.

I would like to thank all our contributing partners and the authors for their tremendous and remarkable efforts. I look forward to continuously building upon our collective expertise in coastal ecosystem restoration by working collaboratively to ensure a successful and integrated ecosystem restoration framework that benefits nature, communities and supports a climate-resilient future.

Foreword

> As a local environmental charity that works closely on the ground, along with esteemed partners and local communities, Emirates Nature-WWF leads multiple Nature-based Solutions projects at marine and coastal ecosystems in the UAE. These projects share the same bottom-line approach: a science-based holistic vision that blends local ecological knowledge with best practices to boost the long-term success of restoration and management efforts.

LAILA MOSTAFA ABDULLATIF
Director General, Emirates Nature-WWF

Nature is a great provider – the source behind the food we eat, the air we breathe and the resources that underpin our businesses and livelihoods. Nature is also one of our greatest allies against climate change, sequestering carbon dioxide from the atmosphere and tucking it away safely within plants and soils, provided we leave these ecosystems unharmed.

Here in the UAE, we are blessed with an abundance of coastal lagoons, filled with mangrove forests and associated habitats. Spanning 27% of the nation's coastline, these lagoons are home to 150 km^2 of mangroves – a testament to decades of passionate conservation and the inherent resilience of these natural ecosystems.

By protecting, restoring and sustainably managing nature through Nature-based Solutions (NbS) we have an immense opportunity to unfurl a canvas of benefits – to bolster biodiversity, fortify climate adaptation and resilience, and pave the way for socioeconomic prosperity. From safeguarding coastal regions against rising sea levels to fostering sustainable growth through opportunities across Blue Carbon, Food Security and Ecotourism – the potential benefits to communities are significant.

That's why it's vital we protect and restore our precious mangroves and their associated habitats as we work towards a net zero, nature-positive future.

As a local environmental charity that works closely on the ground, along with esteemed partners and local communities, Emirates Nature-WWF leads multiple Nature-based Solutions projects at marine and coastal ecosystems in the UAE. These projects share the same bottom-line approach: a science-based holistic vision that blends local ecological knowledge with best practices to boost the long-term success of restoration and management efforts.

This approach recognises the importance of habitat connectivity in carbon sequestration, acknowledging the Blue Carbon significance of not only mangroves, but also associated and often overlooked habitats such as mud flats, saltmarshes and seagrasses. It considers multiple criteria ranging from Blue Carbon potential and biodiversity features to socioeconomic impact on local communities in order to select the most suitable, impactful sites for the implementation of NbS and nature conservation projects.

We are delighted to have embraced this robust scientific approach as part of the Priceless Planet Coalition initiative, which has contributed to the resurgence of mangroves and associated coastal ecosystems at three sites across the UAE. With the support of stakeholders, local communities and Leaders of Change volunteers, the project has successfully restored 50,000 mangroves and achieved a high survival rate for saplings, thanks to intensive long-term monitoring to identify which corrective actions are needed to ensure that mangroves thrive in their new environment.

The learnings and insights gained through this process are reflected in this report, which aims to serve as a beacon for subsequent restoration efforts in the UAE and worldwide, in support of the Mangrove Breakthrough – the joint initiative of the UNFCCC High-Level Climate Champions, the Global Mangrove Alliance and other partners to accelerate the global restoration of mangroves.

This report is the result of the dedication and invaluable support of our esteemed partners, from government agencies to local communities and conservation organisations, who have been instrumental in driving seamless implementation on the ground.

As the world races to accelerate the regeneration of natural habitats, we are optimistic that collaboration, science-driven insight and community involvement will buoy efforts to build a sustainable and resilient future for generations to come.

Acknowledgements

We thank the following contributing authors and reviewers from EAD, EN-WWF and Distant Imagery Solutions: H.E. Ahmed Al Hashimi, Mohammed Al Marzooqi, Maitha Al Hameli, Dr Himansu Das, Nessrine Alzahlawi, Amna Al Mansoori, Gheeda Jaouhari, Stephen Carpenter, Daniel Mateos-Molina, Marina Antonopoulou, Jane Glavan and Cory Rhodes.

We would like to thank the Ministry of Climate Change and Environment (MOCCAE), a strategic partner in this project, as well as other Emirates' local authorities as implementing partners. Their support has been instrumental in implementing restoration efforts on the ground and disseminating valuable insights and recommendations for future work on mangrove and coastal ecosystem restoration. Special acknowledgement is due to H.E. Dr Mohammed Salman Alhammadi, Dr Ebrahim Abdulla Jamali; Hamdah Abdulla Mohammad Al Aslai, Dr Nahla Umer Mezhoud, Dr Majd Mohammed Al Herbawi, Mustafa Abdu Qader Al-Shaer from the Ministry of Climate Change and Environment for their meticulous review of the initial draft, critical comments, and insightful inputs that significantly enhanced the quality of these guidelines.

We would like to thank Mastercard who launched the Priceless Planet Coalition (PPC) to restore 100 million trees globally. PPC is an international initiative created by Mastercard in collaboration with Conservation International (CI) and the World Resources Institute (WRI) that aims to restore global forest ecosystems through 19 restoration projects in various countries including Madagascar, Kenya, the UAE, and others. Emirates Nature-WWF is engaged by Mastercard to lead the restoration work in the UAE as PPC's local implementation partner.

1 INTRODUCTION

Mangrove ecosystems provide several key services including creating shelters for wildlife, providing food and habitat that support fisheries and protecting from coastal erosion and sequestering carbon.

According to the IUCN's first global ecosystem Red List assessment, 50% of mangrove ecosystems units are at risk of collapse and one out of five are at severe risk of collapse, with mangroves in the Arabian Gulf being classified as Vulnerable. Worldwide, these ecosystems are facing multiple threats, with an estimated 25-30% loss in mangrove ecosystems in the last five decades. Forest clearing, dredging, landfilling, coastal development, urbanisation, agriculture, and aquaculture are a few of the human related impacts that mangroves face globally. In many countries, mangrove restoration initiatives are being undertaken to address these challenges and restore the multiple benefits provided by mangrove habitats. However, restoration is often complex and if not well planned or implemented according to science-based methods, they may fail. Furthermore, mature mangrove ecosystems provide significantly more ecosystem services than newly restored or planted areas, and this must be taken into account to ensure avoidance of impact to existing mature mangrove habitats. The emphasis should always be to prioritise protection efforts, avoid impacts, allowing for natural regeneration to take place before moving to assisted restoration and finally planting.

Figure 1.1 Recommended approach to ecosystem restoration and management

Key factors affecting the success of restoration projects are generally inappropriate selection of sites, planting without consideration for hydrological, sedimentation and nutrient factors, plantation of weak and small saplings, insufficient stakeholder engagement and land tenure consideration, selection of immature seeds and lack of post-planting monitoring. Worldwide, it is estimated that around 818,300ha of mangroves could be restored, with global best practice for restoration recommending an ecosystem-based approach, with a focus on long-term ecosystem conservation, improving and restoring the required biophysical conditions that promote mangrove growth, considering habitat connectivity, and ensuring the enabling socio-economic context for mangrove conservation and restoration.

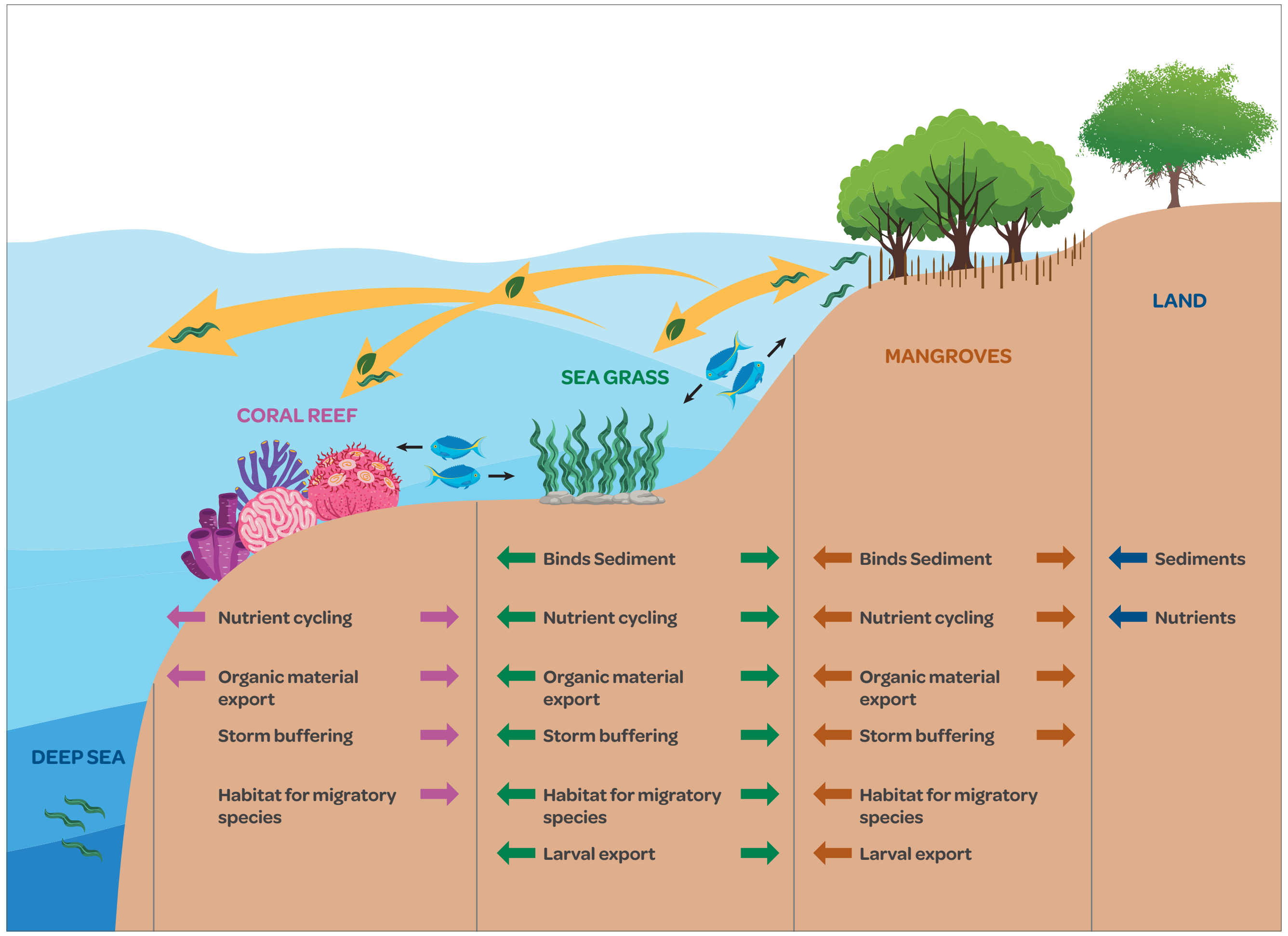


Figure 1.2: Connectivity and Interdependence of Ecosystems along the Seascape (Adapted from Earp *et al.,* 2018)

The United Arab Emirate's goal is to protect existing mangrove ecosystems and their associated coastal habitats, adopt a holistic integrated seascape approach, enhance nature-based solutions, implement ecosystem-based management, ensure that environmental impacts due to human activities are avoided, minimised, and adequately mitigated, and implement evidence-based restoration of key coastal ecosystems when required. These guidelines have been developed collaboratively by the Ministry of Climate Change and Environment, the Environment Agency - Abu Dhabi and Emirates Nature - WWF to guide mangrove restoration in the country and support it with global best practice and evidence. These guidelines will be regularly updated as more data becomes available from implemented restoration projects to continuously adapt practices and tailor recommendations to the local context. Government entities, non-governmental organisations, community groups, corporations and investors seeking to undertake directly or fund mangrove restoration programs in the UAE are encouraged to consult and implement these guidelines as well as review global guidance made available by the Global Mangrove Alliance and other organisations, with further reading recommendations shown at the end of this document.

1.1. BACKGROUND: MANGROVE ECOSYSTEMS IN THE UNITED ARAB EMIRATES

Mangrove forests within the United Arab Emirates are sparse to mid-dense communities that occupy intertidal, low-lying protected shorelines, offshore islands and lagoons, and are composed of a single mangrove species, the Grey Mangrove (*Avicennia marina*). This species is able to withstand and efficiently grow in highly saline conditions, making it one of the most salt-tolerant trees of all mangrove species, with several vital adaptation mechanisms to cope with waterlogging and salinity, such as salt secretion through salt glands located in the leaves. Although it seems likely that a second species, *Rhizophora mucronata* disappeared from the area in historical times, *Avicennia marina* is currently the only species of mangrove that occurs naturally in the UAE.

The genus Avicennia (L.) is named after Avicenna or Abdallah Ibn Sina (980-1037 AD). *A. marina*, commonly known as grey mangrove or white mangrove, has the distinction of being the most widely distributed of all mangrove tree species. The ubiquitous presence in mangrove habitats around the world is due to its ability to grow and reproduce across a broad range of climatic, saline, and tidal conditions and to produce large numbers of buoyant propagules annually. Mangroves can be distinguished into viviparous, crypto-viviparous, and non-viviparous groups. *A. marina* species produces recalcitrant seeds, dispersed by tidal currents. The dispersal unit or propagule of *A. marina* is the fruit, which usually consists of a single embryo surrounded by a thin pericarp . Seeds of *A. marina* are cryptoviviparous and do not have a dormant stage resulting in germination possibility while still attached to the parent plant. *A. marina* seeds possess a hydrophilic pericarp, which is shed upon contact with water. The seeds are dispersed tidally and may remain viable while afloat in agitated seawater, although viability decreases over time.

These forests may grow on muddy substrate, soft bottoms, as well as on rock (coral platforms). The maximum recorded height of mangrove trees in the UAE is 8 meters with an average girth of more than 40 cm for mature trees. Healthy mature trees normally flower between April and June, while seeds ripen during August and October. The naturalised communities are areas of planted mangroves dating more than 40 years, which are hard to distinguish from natural areas. Studies conducted on mangrove soils in the UAE indicated that substrates dominated by fine sand (95%) with some silt and clay (5%) are where most mangrove habitats occur, with mangroves not found on pure sandy beaches or rocky soils. The availability of nutrients such as nitrogen, phosphorus and iron also determine the distribution and occurrence of mangrove ecosystems across the country.

The UAE's Gray mangroves have physiological and genetic adaptations to the harsh environment of the country's intertidal zones, with mechanisms for salt uptake and excretion through specialised glands on the underside of their leaves. The pneumatophores (roots) grow horizontally and are shallow, running for several meters from the tree. These above ground roots allow gas exchange in the anaerobic soil in which the trees grow. The roots allow viable seeds to be trapped and not washed away by the incoming tide, allowing for new growth to be established. These buoyant seeds can remain dormant in the soil for up to a year until suitable conditions are present. It has been observed that highly dense mangrove areas produce less seeds while patchy areas with healthy mature trees produce more, with several other factors affecting seed availability and production at different sites including temperature, health, nutrient availability and freshwater input/salinity, resulting in very variable seed production and availability each year.

Mangrove forests can be found in coastal areas where they are inundated by seawater during the diurnal tidal cycle, which ranges from 0.3m to 2m. The salinity recorded around the mangroves may reach up to 50 ppt, but *Avicennia marina* can tolerate as low as 41 ppt. Sea water temperature varies between 14°C-37°C, while the average air temperature is about 26.8°C, with large variations from summer to winter.

Although mangrove trees are fairly adapted to these variations, high temperatures lead to high evaporation mainly during the summertime months, which may cause a decrease in oxygen levels, thus producing stress on mangrove trees.

The processes that affect the soil quality or composition of coastal areas, such as tidal inundation, evaporation, and rainfall, are key drivers for Abu Dhabi's mangrove growth. Tidal inundation regulates the soil composition by delivering an influx of new nutrients and changing the salinity levels within the substrate. Although mangroves can eliminate excess salt, a salinity above 50 ppt may cause leaves to stress and affect the overall health of mangrove trees. Tidal inundation also regulates oxygen availability for mangrove trees since they are only able to consume the oxygen in the substrate and air. During high tide, pneumatophores are submerged under water, and thus respiration cannot occur. In contrast, during low tide, pneumatophores are exposed to air; therefore, trees are able to consume oxygen up until the next rising tide.

Mangroves are one of the most productive coastal systems, providing ecosystem services for both terrestrial and marine species as well as their surrounding habitats and contributing significantly as primary producers. Mangrove leaf litter provides a vital source of food for many marine and terrestrial species. Leaf litter is further broken down by decomposers such as macrofauna species, which then provide essential inorganic material. Other marine invertebrates consume the mangroves' decomposed matter, producing more food sources for other marine species such as fish and birds. Mangroves also provide shelter and act as nursery grounds for many important juvenile fish, as well as providing breeding grounds for migratory and local birds. Other ecosystem services include carbon storage, coastal stabilisation, water quality improvement, and coastal erosion.

The most commonly found birds within and around mangroves include Greater Flamingo (*Phoenicopterus roseus*), Western Reef Heron (*Egretta gularis*), Grey Heron (*Ardea cinerea*), Western Marsh Harrier (*Circus aeruginosus*), Crab-plover (*Dromas ardeola*), Grey Plover (*Pluvialis squatarola*), Lesser-sand Plover (*Charadrius mongolus*), Dunlin (*Calidris alpine*), and Curlew Sandpiper (*Calidris ferruginea*), some of which have been classified as threatened in the Abu Dhabi Red List of Species. Brachyuran crabs are the dominant group associated with mangrove forests in terms of abundance, with Mottled Crab (*Metopograpsus messor*) and Blue Swimming Crab (*Portunus pelagicus*) as the most common species. Crabs are considered 'ecosystem engineers', playing a significant role in two major ways; (1) by consuming and breaking down leaf litter and (2) increasing oxygen availability in the soil through their burrowing activities, which help develop space for water and thus oxygen within the sediment, indirectly aiding in mangrove growth. Crab abundance is a sign of a healthy mangrove forest ecosystem, although regular mangrove growth can still happen when the abundance of crabs is low. Other marine invertebrates also occur in mangroves such as gastropods, bivalves, and several fish species including: Longtail Silver-biddy (*Gerres longirostris*), Golden Trevally (*Gnathanodon speciosus*), and Ehrenberg's Snapper (*Lutjanus ehrenbergii*).

1.2. MANGROVE CONSERVATION AND RESTORATION GOALS IN THE UNITED ARAB EMIRATES

As of 2024, 201 km² of mangroves have been mapped across the UAE of which 176 km² are in the Emirate of Abu Dhabi, with this extent including both planted and natural mangroves. Mangroves in Abu Dhabi Emirate have been classified as Endangered by the Abu Dhabi Red list of Ecosystems (2022), despite having an increase in extent due to evidence of threatening processes such as coastal development likely to cause declines in natural mangrove ecosystems within the next 20 years. Mangroves, along with all natural habitats are protected by federal law 23 and 24 (1999) and extensive monitoring and rehabilitation programs have been undertaken to ensure their protection and restoration. These include restoration programs across degraded areas, comprehensive forest assessments and monitoring to build and strengthen conservation management plans.

Mangrove restoration efforts in the United Arab Emirates began in the early 1970s, with the late Sheikh Zayed directing the first restoration projects along the Abu Dhabi coast. Coastal development remains the key pressure on natural mangrove habitats with mapping studies indicating a loss of natural mangroves in the Emirate of Abu Dhabi but an increase in planted areas, resulting in an overall increase in mangrove extent.

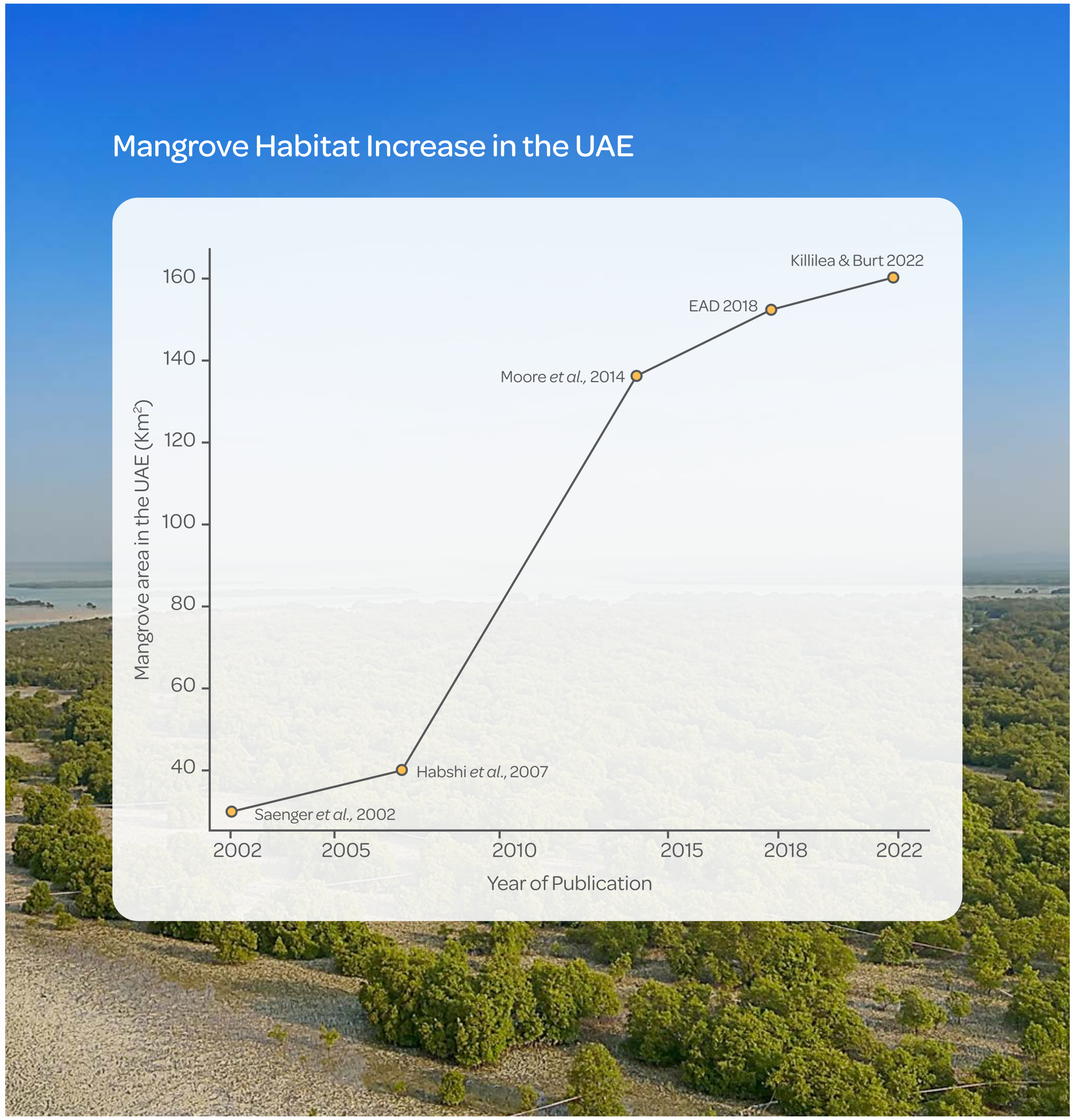


Figure 1.3: Mangrove habitat increase in the UAE, Data assembled from: Saenger *et al.,* (2002), Al Habshi *et al.,* (2007), Moore *et al.,* (2014), Environment Agency - Abu Dhabi (EAD, 2018), Killilea and Burt (in prep), adapted from Burt (Ed.), 2023

Planted areas may not always provide the same ecosystem services as natural areas, with plantations taking an estimated 15-20 years to mature. This is why the UAE's policy as stated in the National Environmental Policy (2020) is to ensure conservation of natural habitats and prevent any further loss. In Abu Dhabi Emirate, policies have emphasised and prioritised the conservation of natural habitats through integrating key critical habitats in land use plans in cooperation with urban and rural planning authorities, in accordance with the Abu Dhabi Emirate Habitat Classification and Protection Guideline, published in 2017 and updated in 2024.

The UAE has been implementing action plans for the protection of mangroves to ensure their long-term conservation and restoration. Actions include comprehensive assessments, rehabilitation programmes, long-term monitoring, habitat mapping of distribution and change detection, development of conservation strategies and management, and ensuring that mangroves along with other coastal habitats are protected in local level and national level regulations and policies.

1.3. PURPOSE AND SCOPE OF THE GUIDELINE

Successful mangrove restoration results in the establishment of a functional restored mangrove forest that is self-sustaining. The purpose of these guidelines is to ensure that all mangrove restoration activities in the United Arab Emirates are science-based, planned and implemented according to best practice, have clear objectives and successful restoration outcomes and support an integrated seascape approach where the function and interconnectivity of all natural coastal ecosystems is considered. Mangrove restoration, while it has clear benefits in some cases, should not adversely affect existing natural habitat nor should it impact the natural regeneration of existing mangroves. Habitat types such as saltmarsh and intertidal mudflats provide important ecosystem services including carbon sequestration and serving as key feeding and roosting areas for wading bird species (*e.g.,* stints, plovers, sandpipers and godwits), and thus should not be converted to different habitat types. The objective of any mangrove restoration program should be to enhance recovery and remove the pressures from existing mangrove areas as opposed to creating mangroves in areas where they did not previously occur. Mangrove restoration need not always include planting, and in many cases planting may not be needed or beneficial.

To ensure that mangrove restoration is carried out according to best practice a permit for all types of mangrove seed collection and restoration activities (that may or may not include planting) is required in certain jurisdictions such as Abu Dhabi Emirate.

These guidelines for the restoration of mangroves in the UAE aim to promote best practice and effective and sustainable restoration practices, while ensuring efficiency, cost-effectiveness, and environmental soundness. The guidelines also serve to guide data collection, monitor outcomes, and adapt strategies, enabling continuous learning to inform future restoration actions. By applying insights gained from monitoring and evaluation, practitioners can refine approaches, increasing the effectiveness and success of restoration efforts over time.

These guidelines address the below topics:

1. Phases and steps in planning a restoration project
2. General guidelines on intervention methods
3. Recommended methods of post-restoration monitoring and community engagement

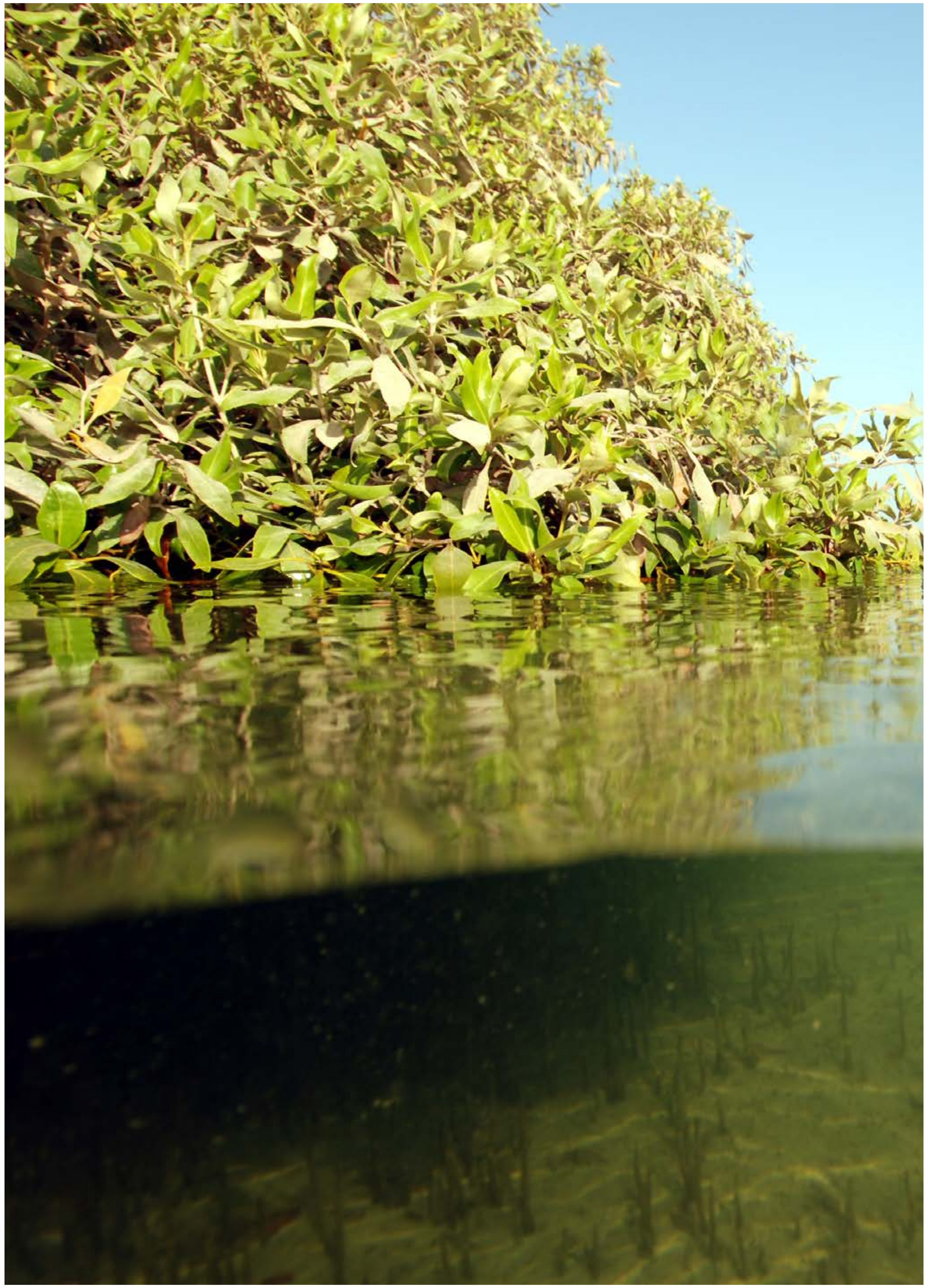


Figure 1.4 Representation of healthy mangroves in Bu Tinah Island, Abu Dhabi, United Arab Emirates

2

KEY PHASES OF MANGROVE RESTORATION PLANNING

2.1 PLANNING A SUCCESSFUL RESTORATION PROJECT

Identifying the objectives of the restoration project is the first step for successful restoration. Objectives might vary depending on the site and the stakeholders involved and will directly influence the planning and scale of the project.

Objectives may include restoring habitat function, addressing existing pressures, restoring hydrodynamic regime and tidal inundation, increasing density in areas where mangrove trees have been removed or affected, or to restore an area to a baseline state with restoration targets clearly identified before embarking on the project.

A needs assessment should be conducted to identify sites requiring restoration, gather historical information and information on future land-use, and defining the objectives of the restoration program before any plan is set.

The following essential points must be considered before planning and undertaking mangrove restoration:

a. Overall goals and specific objectives of the restoration program
b. Origin of disturbances for which mangroves are lost and degraded. Is the disturbance irreversible? Is the disturbance ongoing? What is the current land tenure and future planned land-use for the site?
c. Cost, long-term protection and monitoring
d. Involvement of communities, stakeholders, corporate and government entities
e. Outreach activities and awareness programs
f. Verified qualifications and ecological/scientific expertise in restoration amongst the project team members to ensure success

A comprehensive and well-informed mangrove restoration plan incorporating all the above must be developed in advance, with the overall aim of ensuring the long-term hydrological and environmental conditions that will allow natural colonisation and recovery.

Figure 2.1 Representation of a successful mangrove plantation (Abu Dhabi, United Arab Emirates)

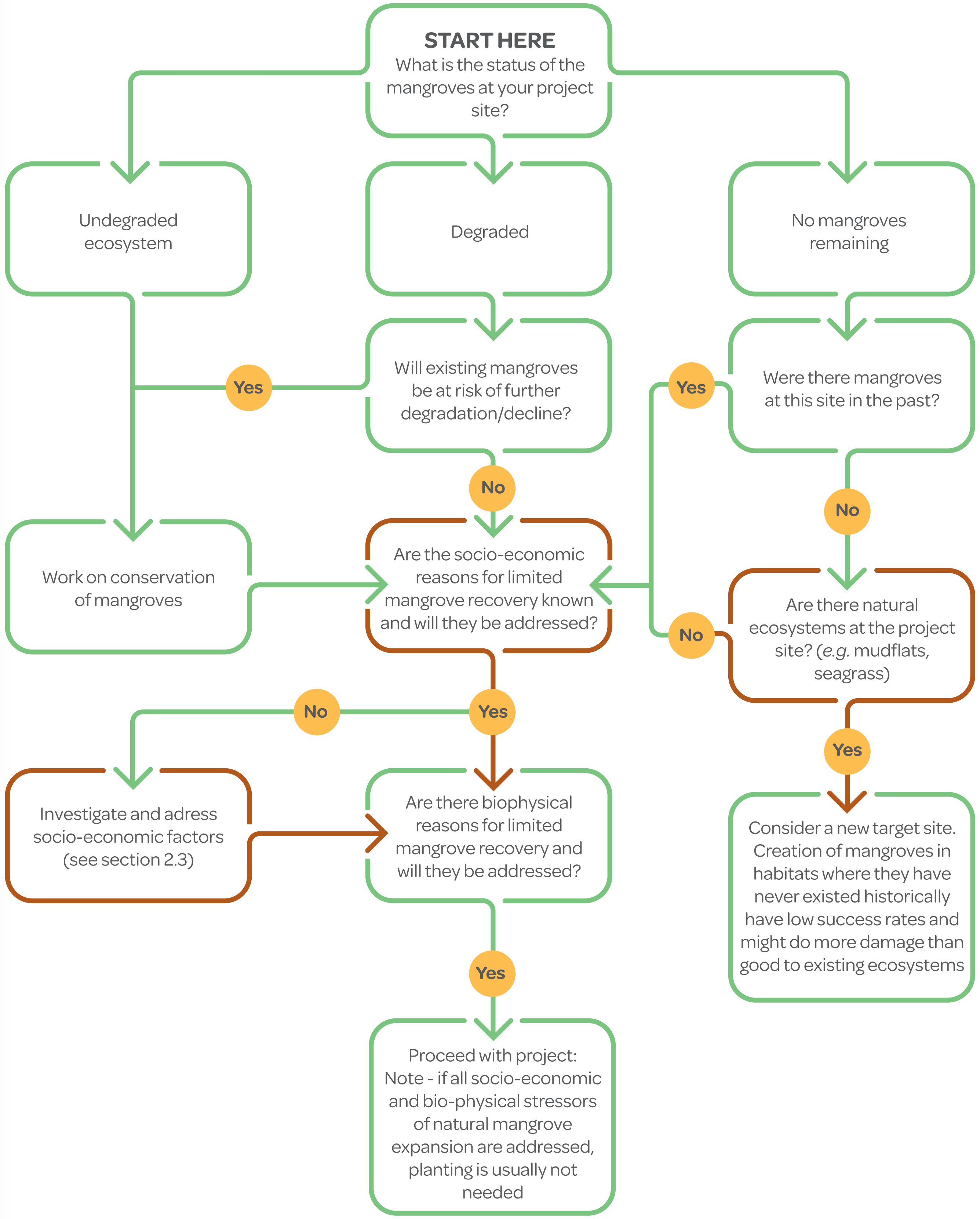


Figure 2.2: Recommended approach for restoration planning. Adapted from the Best Practice Guidelines for Mangrove Restoration by the Global Mangrove Alliance (Beeston, M. *et al.*, 2023)

Table 2.1. Comparison of restoration methods

	Drone dispersal	Nursery grown saplings	Direct seed sowing
Status	Relatively new	Most-common	Common
Cost & Time	Lower cost and time requirement for large scale projects	High cost and time requirement	Medium Cost, High time requirement
Labour	Low intensity	High Intensity	Medium Intensity
Success	≅45%*	>60%*	>50%*

* Based on preliminary monitoring reports (6 months to 2 years) across different sites in Abu Dhabi Emirate

2.2 PHASE 1: RESTORATION NEEDS ASSESSMENT AND SITE SELECTION

Phase 1: Site Selection

The success of mangrove restoration projects mainly depends on the careful selection of appropriate sites (Table 2.2). This selection process is a nuanced task that goes far beyond simply identifying areas where mangroves can physically grow. It involves a detailed understanding of the dynamic interactions among various factors all of which are crucial for ensuring a sustainable and effective restoration effort.

To support this process, a comprehensive set of criteria has been developed, specifically tailored for UAE projects. These criteria are categorised into three levels of priority: high, medium, and low, as detailed in Tables 2.2 to 2.4. The success rate of a restoration project is expected to be higher for sites that meet more of these criteria, especially those classified as high priority.

The criteria are designed to be flexible and applicable to a range of restoration techniques, including seed planting, sapling planting, assisted natural regeneration, and drone seeding. More details on the restoration techniques are provided in Section 2.4.

Table 2.2. High Priority Criteria for Evaluating Site Suitability for Mangrove Restoration in the UAE

Criteria	Description	Guiding Questions (Y/N) (Yes, suggests the criteria is met)
High Priority		
Land Tenure / Future Plans	Assessing land tenure in mangrove restoration projects is needed to understand ownership, legal rights, and customary practices, which are key to the project's feasibility and long-term success. This assessment ensures that activities align with legal, social, and regulatory frameworks, facilitating sustainable management and community engagement. *Assessment type: Stakeholder meetings*	*Did the landowner confirm that there are no future developments planned at the site?* *Is it a protected area?*
Regularly Inundated	Regular inundation is crucial for the health and growth of mangrove ecosystems, as it ensures adequate water and nutrient supply. *Assessment type: Desktop review and field visit*	*Is the site regularly inundated?* *Does the water reach 1.5m or below for 3 to 4 hours, twice a day?*
Soil/Water conditions that Support Mangroves* *More information on these conditions is provided in Annex D	The right soil conditions are essential for mangrove growth. This includes appropriate soil composition and texture, which support healthy root development and water filtration. *Assessment type: Field visit*	*Is the substrate muddy/silty and contains spongy to well-drained, organic-rich soils?*
Promote Large Mangrove Patch Sizes	Choosing sites near existing mangroves can enhance ecological connectivity and provide better chances for successful restoration through natural seed dispersal and habitat expansion. Large patches of mangroves are also associated with larger carbon stores. *Assessment type: Desktop review*	*Is the site located near existing mangroves?*
Avoid Ecologically Important Mudflats* *More information on how to determine ecologically important mudflats is provided in Annex C	It is crucial to avoid restoring mangroves in mudflats that are ecologically significant, especially those serving as crucial habitats for wildlife, including waterbirds. These areas often play a key role in the broader ecosystem and should be preserved in their natural state. *Assessment type: Desktop review and field visit*	*Is the site located away from ecologically significant habitat, such as mudflats?*
Avoid Naturally Regenerating Areas	Restoring mangroves in naturally regenerating areas may be unnecessary and potentially disruptive, as natural regeneration often leads to more resilient ecosystems. Human intervention could interfere with ecological processes and misallocate resources better used in areas where mangroves are not recovering on their own. Monitoring and protecting these areas from external threats can be more beneficial than active restoration. *Assessment type: Desktop review and field visit*	*Does historical satellite imagery confirm that the potential area has no / very slow natural regeneration over time?* *Is this confirmed by observations in the field?*

Table 2.3. Medium Priority Criteria for Evaluating Site Suitability for Mangrove Restoration in the UAE

Criteria	Description	Guiding Questions (Y/N) (Yes, suggests the criteria is met)
Medium Priority		
High Ecosystem Connectivity	Ensuring the restoration site is connected to existing healthy ecosystems to promote biodiversity and ecological resilience. A close proximity to seagrass and saltmarshes has also been linked with an increase in carbon storage. *Assessment type: Desktop review*	*Is the site connected to other existing healthy ecosystems?*
High Ecological Importance	Prioritise sites that have high ecological value or potential to contribute significantly to biodiversity and ecosystem services. *Assessment type: Desktop review and field visit*	*Is the site considered of high ecological value?*
Easily Accessible	Ensure the site is accessible for monitoring, maintenance, and community involvement, which is crucial for the success and sustainability of the project. *Assessment type: Desktop review*	*Is this site easily accessible?*
Upper Intertidal Areas	Restoring areas in the upper intertidal areas is likely to have greater long-term impact as sea-level rise is likely to increase erosion of mangroves at the seaward edge. Upper intertidal areas are also associated with larger carbon stores. *Assessment type: Desktop review and field visit*	*Is this site located in the upper intertidal area?*

Table 2.4. Low Priority Criteria for Evaluating Site Suitability for Mangrove Restoration in the UAE

Criteria	Description	Guiding Questions (Y/N) (Yes, suggests the criteria is met)
Low Priority		
Previously Degraded Lands	This previously degraded lands can be verified using satellite imagery during project consideration and can create a safeguard to ensure that the program does not restore recently cleared mangroves as this could incentivise the clearing of mangrove forests. *Assessment type: Desktop review*	*Was the site previously degraded?*

During the site selection process, field visits are crucial for understanding the on-ground reality and to refine initial assessments, accompanied by local authority representatives or those managing the area. When conducting field visits, it is beneficial to assess the current ecological state and take note of any human activities whilst defining the site boundaries.

Examples of Suitable Sites in the UAE

Four scenarios that exemplify suitable restoration sites in the UAE are listed below.

A variety of scenarios may call for tailored approaches to prioritising criteria in restoration projects. These projects range in scope, from supporting natural regeneration processes in existing seascapes to initiating entirely new artificial mangrove ecosystems. It is important to recognise that each restoration scenario typically possesses its own set of unique characteristics that could change the priorities of certain criteria.

1. **Low Density Mangrove Area** (Example provided in Figure 2.3 - A: Khor Al Yeefrah in Umm Al Quwain): Targeted planting or improvements to the hydrology can significantly enhance a site's potential for natural mangrove seed regeneration. Restoration designs can consider those areas that are less likely to naturally regenerate or that may regenerate slowly, for example in the upper intertidal areas where seed dispersal is less frequent. These sites have an opportunity to prioritise the expansion of existing mangrove areas to elevate carbon stores.

2. **Artificial Sites with Nearby Natural Seed Source** (Example provided in Figure 2.3 - B: Artificial lagoon in Khor Kalba, Sharjah): Whilst inundation may be regular, the soil conditions are less likely to be suitable as they made have been artificially created, especially if there is no evidence of natural regeneration.

Observations of the soil type may indicate how well connected the site is to the natural mangroves, with darker, more spongy soils indicative of an area with more organic soils that are well-connected to the existing mangroves. Organic soils are more likely to increase the changes of seeding or saplings survival and prevent the need for peat to be added. Extending the existing mangroves will also elevate carbon stores.

3. **Upper Intertidal Sites with No Mangroves** (Example provided in Figure 2.3 - C: Selected upper intertidal areas in Al Zorah Natural Reserve in Ajman): These sites are increasingly significant in the context of climate change and rising sea levels. However, if nearby areas do not experience regular inundation, essential for mangrove survival, hydrological adjustments may be necessary. Ensuring consistent inundation is a key priority for successful mangrove establishment in these upper intertidal zones.

4. **Isolated Artificial Sites** (Example provided in Figure 2.3 - D: Mubarraz Island in Abu Dhabi): For these sites the success of the restoration project is predominantly determined by the frequency of inundation and the quality of the soil. Due to their artificial and potentially isolated characteristics, achieving large mangrove patch sizes, a high-priority criterion as outlined in Table 2.3, may not be practical for these sites. Instead, the focus should shift to enhancing the ecological value and establishing connectivity with offshore habitats, such as seagrass areas. This approach aims to increase carbon storage and bolster ecological resilience at the site, adapting to the unique challenges presented by its isolated and artificial nature.

Additional information to elevate carbon storage: Consider restoring saltmarshes in this area to improve connectivity, facilitate greater pool of organic material important for the long-term success of seeds and saplings to survive in the area.

Figure 2.3. Satellite images of each scenario where restoration may be considered or that has occurred *Source: Google Earth (Maxar Technologies, Landsat/ Copernicus)*

Additional parameters to take into account during the site selection process include wave energy and topography. Strong wave energy can uproot young *Avicennia marina*. To avoid this impact, sheltered and low-energy intertidal areas may be selected. In high wave energy areas, stones / woods (locally available non-polluting materials), geo-tubes may be placed temporarily for the first two years of plantation. A proper slope measurement is also important for the site selection using field-based surveys and/or digital elevation models.

Table 2.5: Where to AVOID planting mangroves

	Where	Justification
1	Natural tidal flats where mangroves do not naturally grow or have not been previously reported to exist	These habitats are unique and used by birds for foraging. Tidal flats are natural ecosystems. Planting mangroves on tidal flats will modify the ecological character of the existing habitat and disturb naturalness and distribution of species living therein, thereby not resulting in a net gain of biodiversity
2	Other coastal communities namely mudflats, sabkha, algal mats, salt marsh, sandy beaches	These are critical coastal ecosystems with unique ecosystem values, including carbon sequestration, and should not be converted to mangroves
3	Sites with ongoing activities leading to pressure on coastal area and/or mangrove ecosystem	Attempting to plant or restore mangroves in areas with ongoing threats will decrease chances of growth and success
4	Sites earmarked for future development or land use	Attempting to plant or restore mangroves in a site identified for future development will result in project failure and waste of resources. Stakeholder engagement with all entities involved in land use planning is recommended prior to undertaking a restoration project

2.3 PHASE 2: DEVELOPING A MANGROVE RESTORATION MANAGEMENT PLAN

As outlined in section 2.2 above, the success of mangrove restoration depends on several key factors including:

1. Site selection and suitability
2. Determining the factors that have caused mangrove degradation and developing response measures to ensure long term health and continued growth at the selected site
3. Developing a restoration plan that takes into account and involves all stakeholders and ensures long term monitoring, accountability and stakeholder engagement to sustain growth and recovery of the site.
4. Working with qualified and experienced restoration scientists and ecologists that are familiar with the local context

After assessing restoration needs and determining site suitability, a restoration plan should be prepared that includes a sufficient description of the methods, location and long-term monitoring plan, clearly stating the objectives of the program. The restoration plan should include a description of environmental baseline conditions, the predicted benefits and impacts of the proposed project, and the associated monitoring efforts for the proposed site.

The plan should provide a clear justification for the project with the projected net ecological benefits. Table 2.7 below outlines a recommended structure and content for this plan.

Table 2.6: Recommended methods of interventions depending on site conditions

Description	Required interventions	Recommended Planting Methods where applicable
Lost and degraded mangrove areas	Land preparation (soil and hydrological improvement) may be required – Ensuring causes of degradation are well understood and addressed before commencing restoration	Nursery grown saplings, as well as hand and drone sowing
Sparse difficult to reach mangrove areas with limited natural regeneration due to past or current stressors	No land modification required	Drone sowing and/or Nursery grown saplings and hand sowing if area is accessible
Artificial islands and newly developed beaches near or within current or past mangrove areas with suitable soil, topography and hydrology for mangrove growth	All parameters to be studied including beach protection measures and hydrological requirements	Nursery grown saplings preferred over other methods to ensure successful growth

Table 2.7: Recommended Checklist for Mangrove Restoration Plans

Mangrove Restoration Management Plan - Checklist	
Chapter 1—Executive Summary	
☐	Adequate summary of the proposed project with timelines, milestones, key objectives, area, and proponents outlined
Chapter 2—Introduction: What , Where, Who, Why, and How	
☐	The project title, general project description, timeframe, project rationale and justification
☐	Contact details and information about the project proponent and contractors involved, including client/project sponsor
☐	Project team & evidence of prior experience and technical qualifications specialising in restoration and ecological monitoring

Mangrove Restoration Management Plan - Checklist	
Chapter 3—Restoration Program Description and Methods	
☐	Why do we need to restore? Description of the need for the proposed project and expected benefits, justifying the need for intervention
☐	Is my project being planned according to best practice? Assessment of project consistency with key principles of the Abu Dhabi Mangrove Initiative (for Abu Dhabi Emirate) and UAE National Guidelines for Mangrove Restoration, and where possible global best practice guidelines (Global Mangrove Alliance, 2023)
☐	What is at the site? Who do I need to contact to access and secure permissions? Maps and descriptions of the location and scale of the proposed project, restoration site ownership and existing and surrounding land use, habitats presently at the proposed site and habitats surrounding the site (up to 0.5 or 1 km away from the center of the planned site). Justification of site selection and evidence of permission to conduct restoration activities at the site (where applicable)
☐	What happened here? Description of the history of changes of the restoration site and description of the proposed project (method, stakeholders, objectives, timeframe)
☐	What makes this site a suitable candidate for restoration? Description of the restoration site (basis for site selection, ground height level, ground slope, soil type, currents, grazing pressure, natural regeneration, demarcation of restoration site, seedling/seed quantity estimation, sourcing of seeds or saplings, existing or past pressures, site history, *etc.*.). Description of the current environmental conditions (baseline conditions) including land use, habitat type, soil type, flora and fauna. Include base maps, remote sensing and spatial analysis
☐	What does the site need? Description of the restoration methods and work procedures (*e.g.* forms of intervention, land preparation or hydrological improvements, for natural assisted regeneration needs include sourcing of seeds and saplings, transportation of seedlings, spacing, restoration/working time, pit preparation, sapling protection)
☐	Will my restoration activity have an environmental impact? Description of the potential environmental impacts associated with all phases of the proposed project (negative or positive). Identification of project activities during all phases (land preparation, planting, post plantation monitoring, hydrological restoration) that may result in litter, carbon emissions or cause disturbance to biotic communities at and around the site or modify the physical environment. This should include a detailed description of raw materials, equipment/machinery used, pollution anticipated, and wastes generated at all phases of the project
☐	The project status and schedule and project organisational chart
Chapter 4—Monitoring Plan	
☐	How will I measure success? Detailed descriptions of both the short term and long-term monitoring programs, including information on sampling design (frequency, intensity), who is responsible for the monitoring program, and reporting and documentation requirements. Monitoring program objectives, methods, frequency, conditions, and indicators that will be measured as part of the monitoring program
☐	How will I report results? Schedule of the submission of the monitoring data (at minimum every 6 months, 1 year and 2 years) and the long term restoration and ecological monitoring program (5th year and 10th year post restoration)

Mangrove Restoration Management Plan - Checklist	
Annexes	
☐	Annex 1- References
☐	Annex 2- Site map (kmz and shape files) indicating project boundary, existing and surrounding land use
☐	Annex 3- Site photos
☐	Annex 4- Letters of permission from land owner (if applicable)
☐	Annex 5- Evidence of project team prior experience and technical qualifications specialising in ecological restoration
☐	Annex 6- Information on the current condition of the environment (methodology, data, and results)
General Criteria	
☐	Logical organisation of integrated and easy-to-review components, including annexes
☐	Include a list of abbreviations, definition of terms, and full references to sources of information
☐	Include a full suite of detailed maps describing the project site baseline and future projected mangrove habitat cover
☐	Clarity (*i.e.,* minimal technical terms, the adequate and appropriate use of graphics, text could be understood by non- specialists)
☐	Include expected positive and negative impacts of the proposed project (carbon footprint of the restoration activities)

2.4 PHASE 3: IMPLEMENTATION

2.4.1 STAKEHOLDER ENGAGEMENT

Stakeholder and community engagement should occur throughout all phases of the project and in particular in the very early stages when selecting the area, identifying the restoration needs and governance/land tenure and land-uses. Once stakeholder endorsement is obtained for the restoration plan, engagement needs to continue during the implementation phase to ensure all concerned entities, individuals, institutions are involved and informed of the project activities and schedule, and have the opportunity to be involved whenever appropriate. Community and land owner engagement in restoration activities supports the interest in the restoration site and could ensure the enabling long term conditions at the site that help the restoration project succeed. Stakeholders could include federal and sub-national government agencies, global mangrove and nature conservation organisations, academic or research institutions, local residents and business owners, municipal authorities, land developers and landowners. Prior to implementing the project, all necessary and applicable permits for the area need to be obtained. For example, in Abu Dhabi Emirate, a permit from the relevant competent authority is required anytime seeds are collected or restoration projects involving planting or other restoration interventions are planned. Regular meetings and workshops to kickstart the restoration project, clarify roles and responsibilities, update on the project progress and achievements are recommended throughout the restoration cycle.

2.4.2 SITE DELINEATION AND DETAILED MAPPING

Once the restoration plan is set and approved and endorsed by all concerned parties, the restoration site must be clearly demarcated and mapped in detail with the different interventions planned in each area and the timing of these interventions identified. Different forms of intervention might be needed at one site, including hydrological improvements (channel creation or diversion), sediment removal or relocation, or topographical adjustments to ensure tidal flow is restored to natural conditions as much as possible. A study of historical imagery to understand the natural hydrology that was present at the site would help guide the intervention to ensure an environment that would be conducive to natural growth and recovery.

2.4.3 HYDROLOGICAL IMPROVEMENTS (WHERE NECESSARY)

During the development of the restoration plan, the needed interventions at the site would have been identified based on the site history and current state. One key question to ask is "what went wrong" and what does the site need to recover naturally. Asking why the site can't recover without human intervention will help address the causes hindering natural regeneration. Drawing on local communities and stakeholders for ecological knowledge could provide a source of information about the site history and health along with assessments using both remote sensing and field surveys to determine hydrology, hydrodynamics and seed/propagule availability. Nearby reference sites, where available, could provide insight into the needed intervention to restore the biophysical conditions necessary for natural growth. Hydrological monitoring and where possible, hydrodynamic modelling could assess the current conditions and assist in developing a plan to ensure the best possible hydrology for habitat recovery. There are different methods to assessing the hydrology at potential restoration sites, as outlined in Table 2.8 below from the Global Best Practice Guidelines for Mangrove Restoration. Examples of interventions could include modifying the topography through either restoring channels, manual removal of sediment or addition of sediment depending on the conditions, building permeable fences (modifications to soil elevation) to either increase or decrease inundation depending on the site, to ensure optimum tidal inundation times. In cases where mangroves are exposed to strong waves or currents or a change in hydrodynamic conditions due to activities such as dredging, then shoreline restoration activities (sediment nourishment in sandy environments and permeable structures in muddy environments) could provide the sheltering necessary for recovery and establishment of new seedlings. In some cases, natural regeneration could be limited due to lack of habitat connectivity. Restoring hydrological connectivity between sites so seeds/propagules are delivered during high tide would aid in these conditions. Ultimately, the implementation of the needed interventions will depend on the needs identified for the site, with the key recommendation being to take the time to understand and study the biophysical conditions of the area before moving ahead with implementation.

Table 2.8. Approaches to assessing hydrology and hydroperiods at restoration sites. Adapted from the Best Practice Guidelines for Mangrove Restoration by the Global Mangrove Alliance (Beeston, M. *et al.,* 2023)

Method	Description	Benefit	Issues	Cost	Source
Consultation	Talking with local communities and looking at historic maps	Cost effective and involves community engagement	Has the potential for low accuracy and best at a scale	Low	Lewis and Brown, 2014
Elevation/ inundation	Comparison of elevation in restoration and reference sites	Cost effective and can involve community engagement	Can be low resolution and has potential for low accuracy. Small scale	Low	Lewis and Brown, 2014 Oh *et al.,* 2017 Teutli-Hernandez *et al.,* 2020
Model - Lidar / Digital Elevation Model (DEM)	Compare elevation of restoration sites to elevation of natural mangroves using Lidar DEM data using appropriate software (*e.g.,* ARC GIS or similar) A catchment elevation map can help identify restoration opportunities	Data available at large spatial scales at moderate to high resolution for site bathymetry/ elevation with minimal on-site effort required. Can be large scale	Limited data availability for many priority restoration areas. Involves complex analysis requiring specialised programs and expertise. Expensive to acquire if not freely available	High	Maher *et al.,* 2013
Mini buoys	Tilt sensors housed in a small float (mini buoy) to monitor inundation, tidal currents, and wave action at restoration site. Non-vented pressure sensors to measure water levels only	Accurate integrated and cost-effective hydrological and hydrodynamic monitoring in shallow water	Assessing local hydrology and hydrodynamics prior to restoration against local references. Small scale	Low/Mid	Balke *et al.,* 2021

2.4.4 SEED OR SAPLING SOURCING (WHERE PLANTING IS DEEMED NECESSARY)

As part of the implementation plan, the source of seeds or saplings needs to be identified in cases where planting is deemed necessary. Planting should only be done in impacted areas where natural regeneration is observed to be low or non-existent, and where site conditions are conducive to growth or can be restored to allow for settlement and growth. The method of planting deemed most suitable for the site would have been predetermined in the restoration plan developed previously. Seeds will have to be collected in the case of drone dispersal and direct seed sowing, while saplings can be sourced from established nurseries for traditional planting of saplings. In all cases, it is recommended to plant seeds and saplings that originate from the same location or as close as possible to the restoration site, to ensure the genetic integrity of the area is maintained as mangroves in different locations will have different site-specific adaptations depending on the local conditions. Seed collection must be done according to all applicable local regulations and permitting requirements and must not damage habitats or affect natural regeneration. It is essential to ensure that the seeds are not being over harvested from an area, and that those collecting the seeds are trained on how to collect, store and transport viable healthy seeds in a manner that does not damage the seeds or affect natural habitats

The establishment of mangrove nurseries can support mangrove restoration projects. In this phase, seeds collected from mature mangrove forest are raised into seedlings and then into saplings. The saplings are then planted at the desired location. Mangrove nurseries can either be in a greenhouse or coastal area. Greenhouse nurseries are used to propagate mangroves in a controlled environment, which can result in faster growth rates and higher survival rates. However, greenhouse nurseries can be expensive to establish and maintain. Coastal nurseries, on the other hand, are established in tidal flat areas along the coast. Coastal nurseries can be less expensive to establish and maintain than greenhouse nurseries, but they may require more labour and management. Two types of mangrove nurseries are used for growing mangrove saplings of *Avicennia marina* species in the UAE: (a) inter-tidal nursery, and (b) supra-tidal or upland nursery. The inter-tidal nursery is developed in an inter-tidal area, and saplings in nursery pots are subjected to natural tidal inundation. The supra-tidal nursery is made upland away from the high tide line. The water requirement for supra-tidal nursery is seawater or brackish water (by mixing fresh water with seawater in different proportions in high salinity areas) to be pumped to water the plants twice a day. During the first month, seedlings should be watered twice daily with a mixture of seawater and freshwater (1:1); afterwards, once daily seawater watering is sufficient. Upland nurseries allow for providing freshwater, allowing rapid growth, but leads to salinity shock once the saplings are planted. For the UAE, tidal nurseries are recommended with no need for freshwater, saving water resources, and with better survival once planted. Studies show that in inter-tidal nurseries, seedling establishment and survival rate are variable and relatively low. This is mainly due to high tidal wave action that potentially washes the seeds away. In contrast, research results from supra-tidal nursery suggest high success rates. The approach in nursery pot preparation, nursery bed and daily monitoring of plantations in both types remain the same. In inter-tidal zones, the plants are exposed to regular tidal wave action and are often submerged in saltwater for several hours each day. This can limit their growth and productivity, as they need to conserve resources to survive in this harsh environment. In contrast, plants in supra-tidal areas are not subjected to the same regular tidal wave action and are not submerged in saltwater for extended periods. They can access more resources, including sunlight, fresh water, and nutrients, which can promote their growth and productivity. In supra-tidal areas, mangroves tend to grow taller and produce more leaves and branches than those in inter-tidal zones. However, plants in inter-tidal zones are more efficient at utilising resources and have a higher rate of carbon fixation, which is the process by which plants convert carbon dioxide into organic compounds.

Table 2.9. Comparison between supra-tidal and intertidal nursery of mangroves

Parameters	Supra–tidal (Upland) Nursery	Intertidal Nursery
Location	Upland	Intertidal
Water	Brackish water and sea water	Natural Sea water /inundation
Growth	~60 cm in 6 months	~30-40 cm in 6 months
Sediment in nursery pot	Soil with sand, silt, and organics	Soil with sand, silt, and organics
Survival in nursery	High	Relatively low
Survival post-plantation	Relatively low	High
Cost	Relatively high (machinery and infrastructure)	Less compared to upland nursery

The establishment of a mangrove nursery requires the following key requirements:

A. Selection of site: For intertidal nursery, an intertidal area along the coast with regular inundation is required an area of 100m X 30m (for 500,000) saplings. For supra-tidal or upland nursery, facility for electricity, water is required for a levelled space of the same size. The site should be easily accessible.

B. Nursery beds: A nursery bed measuring 6 x 1.2 m will accommodate about 1,000 container plants. The nursery site should be cleared of any debris that could interfere with operations. The nursery beds must be levelled perfectly in order to achieve an even distribution of water.

C. Pots: typically, plastic potting bags. However, raising seedlings in degradable polythene bags (measuring 26 x 13 cm) is more appropriate. Plastic pots are expensive and difficult to recycle. However, if wisely used, the plastic pots can be used a few times. Four holes should be punched in the polythene bags to allow aeration of the plant root zone.

D. Soil media: Sea sand from the same area where seeds were collected can be used. However, it's important to note that not all sea sand is suitable for use in a nursery. Some types of sea sand may contain high levels of salt or other contaminants that can be harmful to the seedlings, if sourced from areas other than mangrove habitats.

E. Seed/propagules collection: Mangrove seeds/ propagules are collected during the peak of their reproductive season, which varies depending on the species and location. However, in the UAE, mangrove seeds are usually ripe and ready for collection from mid-August to mid-October. Fully mature and good quality seeds or propagules (pre-germinated seeds while still attached to the mother tree) are a prerequisite for raising healthy planting stock. The seed / propagules are directly plucked from the mother trees or fallen seed can also be collected from the ground. It's worth noting that the collection of mangrove seeds should be done in a sustainable manner that does not harm the trees (branches, flowers and unripe seed) or their surrounding

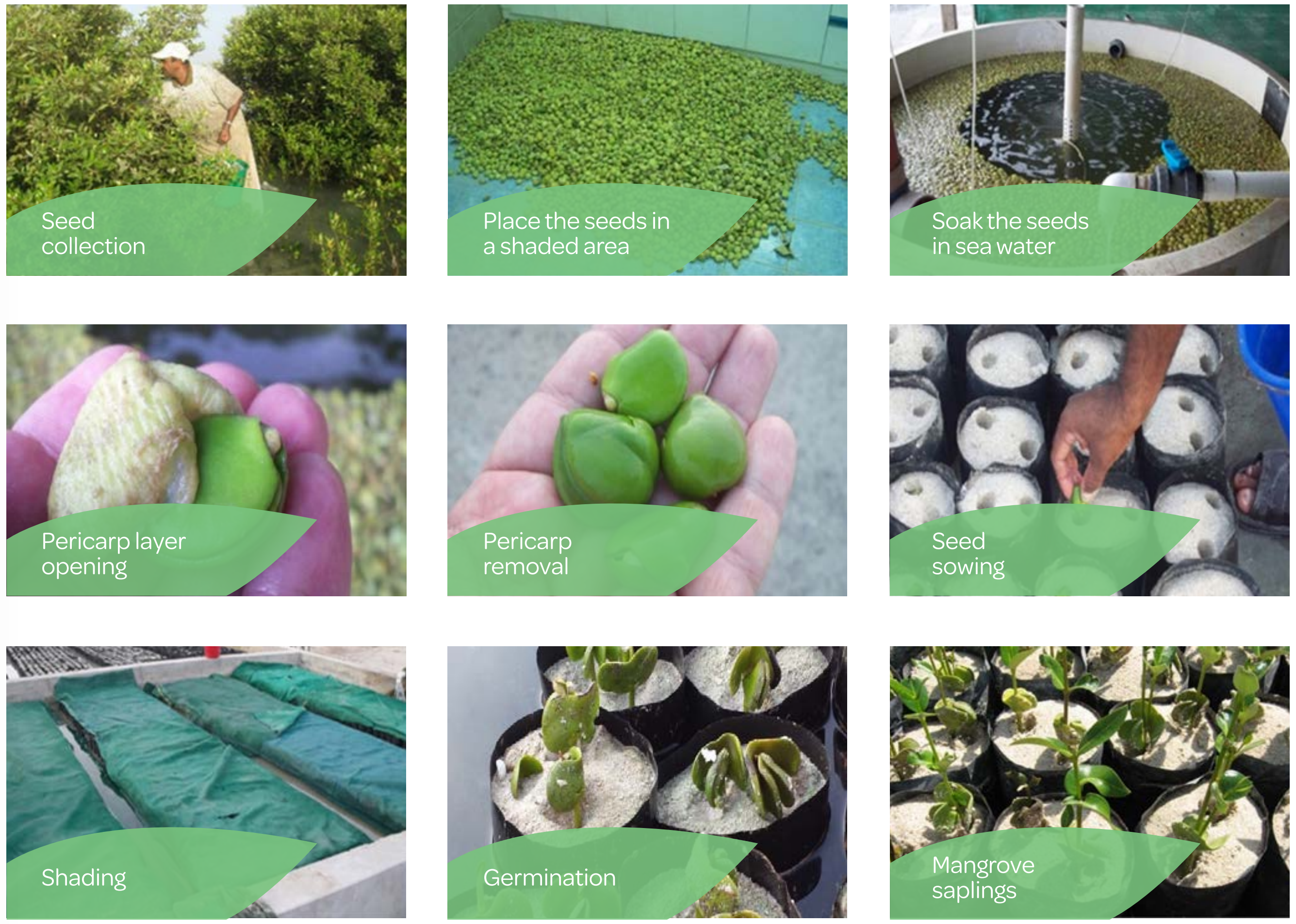


Figure 2.4: Steps for nursery establishment, from seed collection to growing saplings

ecosystems. In addition, any harvesting of mangrove seeds should be done in accordance with local laws and regulations, and with the permission of relevant authorities and landowners. It is important to note that not all the available seeds can be collected from an area, as it will disrupt the natural regeneration process of the forest which eventually affect the natural ecosystem. Therefore, it is recommended to limit seed collection to a maximum of 20% of the area in order to avoid causing negative effects on the forest. This way, the remaining seeds can be left to naturally regenerate the forest and support the ecosystem.

F. Seed Selection: *Avicennia marina* seed weighing around 10gm preferable to be selected. It is important to select, fresh, mature, full size, and healthy seed / propagules, free of any disease, pests and injury.

G. Sowing of seeds: *A. marina* seeds should be soaked overnight with seawater to hasten the opening of fruits and the splitting of their seed coat respectively.

It is recommended that seed collection and nursery sowing operations should be organised in such a way that seed sowing is completed within 48 hours of seed collection. Therefore, collection of seeds and sowing into bags are done simultaneously. As an example, if the seeds are collected on first day (D1), sowing will be done on the second day (D2). Upon collection of seeds on D1, they will be kept in seawater overnight. On D2, the skin of the seeds has peeled off and subsequently sowing will be done. Mangrove seeds should be sown in plastic pots / degradable polythene bags present in the nursery beds. Pots filled with soil should be watered thoroughly before sowing. Usually, one seed per pot or bag is sown. However, if expected initial seedling survival in the nursery is low, or field plantation site conditions are poor, two or more seeds per pot may be used. For direct planting of propagules it is important to plant the seed at the appropriate depth to ensure proper germination and growth. The radicle, which is the embryonic root of the plant, should be planted about one-third of the way into the soil. This will provide the seed with the necessary moisture and nutrients for germination without burying it too deeply.

H. Storage of seeds: If seed / propagules are to be stored for longer periods (although not more than five days for *A. marina*), they should be kept in buckets fully immersed in seawater. The buckets should be kept in a well-ventilated, shaded place, preferably in an air-conditioned room.

I. Shading: To avoid sunburn, it is necessary to shade newly sown seeds / propagules. Construction of a shade-house is one option if large numbers of container plants are to be raised continuously over a longer period. Otherwise, plastic shading nets may be used for covering the nursery beds.

J. Sapling plantation: Mangrove saplings are ready for transplantation into their permanent planting sites after 6-8 months of sowing.

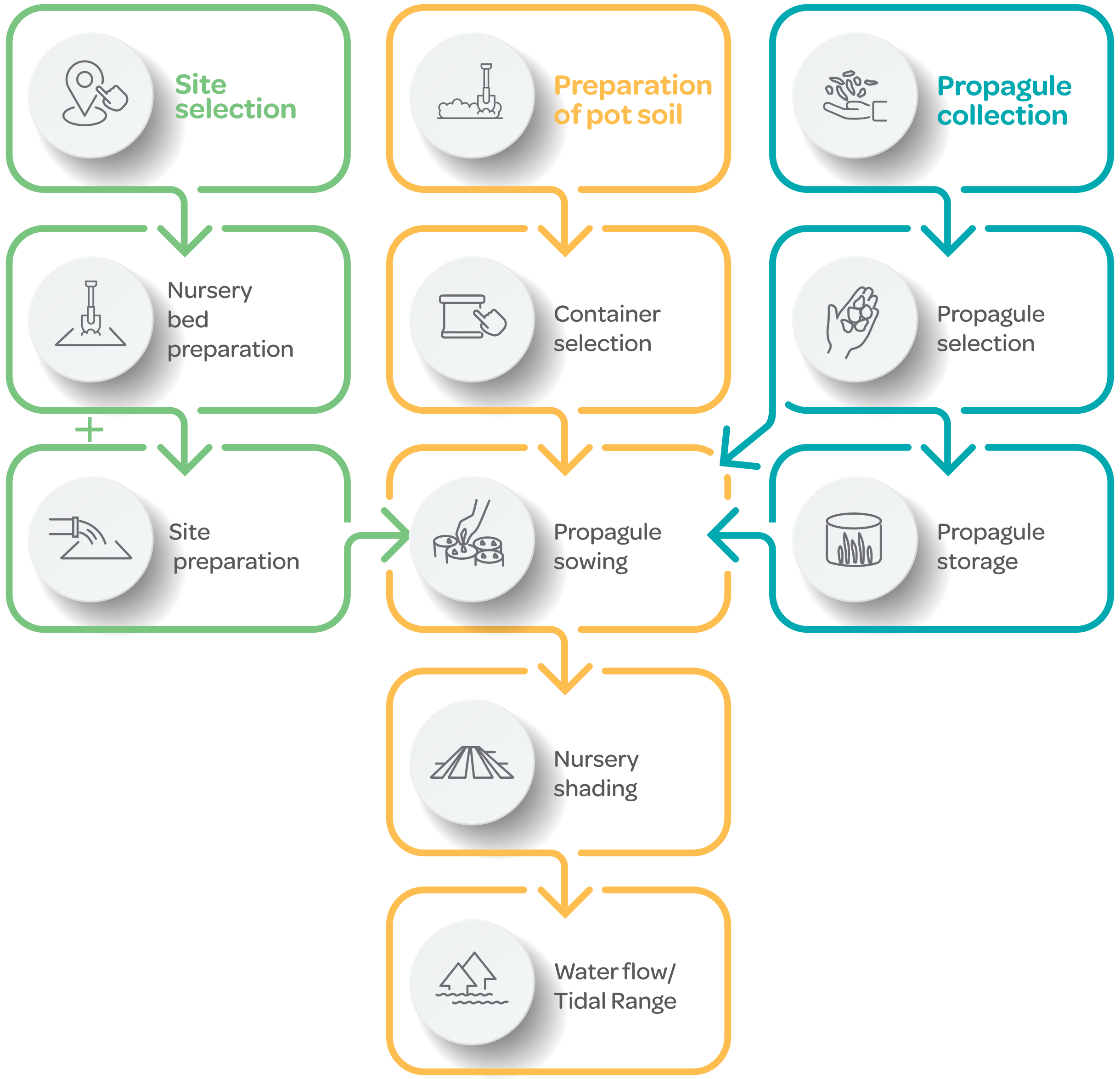


Figure 2.5. General representation of mangrove nursery workflow

2.4.5 PLANTING

DRONE SEED DISPERSAL

Internationally, drone technology has transformed the approach to habitat restoration projects in terrestrial and coastal areas that have experienced large-scale degradation or environmental effects such as forest fires or flooding. Drones can be used to disperse seeds over large areas of degraded forests, aiding in the restoration of these vital ecosystems. By combining aerial seed dispersal with monitoring techniques, such as using drones to track seedling growth and survival rates, researchers can gain valuable insights into the effectiveness of restoration efforts and make informed decisions on future conservation strategies. Furthermore, through the use of drones, ecologists and drone experts can furthermore collect data, monitor progress, and execute restoration strategies efficiently and affordably.

Mangrove seed dispersal though drones is a new innovative method for cost efficient assisted natural regeneration trialled in Abu Dhabi and has shown relatively good success rates, allowing mangrove restoration to be conducted at larger scales and in less time, and potentially reaching more remote sites. By mapping mangrove ecosystems, monitoring growth patterns, and addressing deforestation in coastal regions, drones can be a revolutionising way to approach mangrove restoration projects. Drones can further capture images and videos of restoration sites pre- and post-planting, enabling ecologists to evaluate ecosystem health and pinpoint areas ideal for restoration, requiring further attention, or areas for replenishment as needed. This real-time information empowers ecologists and drone pilots to make informed decisions and effectively prioritise the locations and patterns of their restoration efforts. Finally, drones can now create highly accurate 3D maps of mangrove forests, allowing researchers and restoration teams to understand the layout of the ecosystem better and plan their efforts accordingly.

Drone dispersal should consider the seasonality of seeds and the limited time for seed storage, as well as ensure that all formal permissions for drone flights and NOCs have been obtained. Harvesting and preparing the propagules are critical parts of using drones to disperse seeds for restoration. The outcome of the restoration project significantly relies on the quality of seeds harvested and how they are readied for dispersal. After selecting the seeds, proper preparation is necessary before dispersal. This might involve further germinating the seeds to boost germination rates, removing any impurities, and ensuring they are suitable in size and weight for dispersal. Specialised tools may be required to process and prepare these seeds for dispersal.

Drone-led mangrove restoration methodology involves healthy seeds being dispersed in selected areas using adapted off-the-shelf drones or custom-built drones with an adapted rigging mechanism to disperse the seeds at high speed to ensure a high stick rate. The drones should be selected or built for long-range and long battery life to maximise the benefits of drone use as well as autonomous flight, given the flights will be out of line of site. A focus should be placed on the quality of the seed dispersal rather than the rate of dispersal so that the effectiveness of the approach is optimised.

This methodology has resulted in a more cost-effective restoration process. The survival rate of the planted mangroves is estimated to be much lower than some estimated traditional planting methods. Initial monitoring reports point at an average 40% success rate for the first round of planting and a less than 2% die-off after 5 years of data if left undisturbed with no anthropogenic activities occurring.

Assisted natural regeneration using drones can provide benefits depending on the context, including:

- Access to remote areas or hard to reach areas
- Access to remote areas that are difficult to work in or higher risk of injury
- Rapid seeding at large scale
- Lower costs through the life cycle of the restoration projects
- Less impact on the natural habitats from the restoration activity
- Rapid reseeding of areas that have faced impact events

Considerations before undertaking mangrove restoration using drones:

- Site suitability assessment needs to be carried out regardless of restoration methodology, including assessing soil characteristics, nearby habitat types, and adequate fine scale mapping of the seeding area with extensive groundtruthing
- Requirement for seed collection and ensuring suitable timing
- To understand and abide by all General Civil Aviation Authority (GCAA) requirements and drone permissions
- To understand ecological principles and only create planting patterns align with these principles
- Seed processing requirements, including pre-germination
- To either purchase off the shelf drones to be modified or custom build the drones with both having optimised length of flight time and battery duration
- To modify or build a rigging dispersal mechanism that allows the seeds to be embedded in the soil and maintain integrity and non-bruising of the propagule
- To program the drone flights for efficient seed dispersal that avoids unsuitable habitats (mudflats, already planted areas, forested areas, channels and water areas etc.)
- To optimise the possibilities of AI and machine learning in the ability to automate processes, analysing the data collected by drones, and the creation of algorithms to support restoration methodology and monitoring
- To optimise flight planting time so that it reflects tides and environmental conditions
- To conduct small scale trials not exceeding 10 hectares for the full methodology of mangrove restoration through drones before undertaking large scale projects
- To undertake full monitoring counts rather than extrapolation of plots for the success rates of the sites and as per EAD guidelines with both seedling height and number of leaves also obtained
- To monitor and assess the percentage of success rates for the project and improving the techniques prior to moving forward with large scale drone dispersal with the same monitoring methodologies proposed in this guideline and ensuring sufficient statistical representation, with a minimum monitored area of 10% of the total site
- To monitor success of plantation and map the habitat restored by drone and through field surveys for ground truthing as well as positive ecosystem change

HAND SOWING OF SEEDS

Hand sowing of healthy mangrove seeds of *Avicennia marina* can be a relatively cost-effective planting method. However, this method has not been tested for its success, neither tried extensively in the region.

Avicennia propagules or seeds can be planted directly into the substrate in the intertidal spaces of sheltered sites. If done correctly, this method is more cost-effective and easier than using a nursery, but often fails due to incorrect methods of planting and timely monitoring.

The process involves, (a) selection of healthy seeds, (b) dispersal / planting of seeds two meters apart from each other in an intertidal area, and (c) monitoring the site every month for the first 3 months and half-yearly thereafter.

Seeds must be pushed half of their length into the substrate. When planting in the ground, place the lower wider half of the propagule into the substrate. One of the most common reasons for failure using direct planting is that the seeds are pushed too deep into the substrate preventing them from being able to breathe and leading to plantation failure.

PLANTING OF SAPLINGS

Nursery-raised saplings should be planted at the appropriate density and spacing, and care should be taken to ensure that they are planted at the correct depth. The recommended optimal density varies among experts and studies, ranging from 1 plant per square meters to a 2-meter spacing between plants. As a standard practice, it is recommended to ensure no overplanting of a site to ensure the space requirements for planted seedlings to grow successfully and survive in the long term.

The main steps for transplanting mangrove nursery-raised saplings are as follows:

- **Transportation to the planting site:** The saplings should be transported carefully from the nursery to the plantation site without damaging their roots or stems. It's essential to minimise any stress or damage to the plants by ensuring that the saplings are transported as quickly as possible. Plan the travel in such a way that the arrival time at the planting site is at least one hour before the tide becomes low enough to start planting.
- **Site preparation:** Clear any debris or obstacles from the planting area. Dig holes deep enough to accommodate the root system of each mangrove seedling. The spacing and planting pattern may vary depending on the technical assessment of the selected site and the planting techniques, with the objective to try and replicate natural regeneration patterns where possible, support variation and microbiodiversity.
- **Planting the saplings:** Gently remove the plant from the bag, keeping the soil attached, and place it inside the hole. Ensure that each sapling is planted at the same level as the ground. Backfill the holes with soil and water the seedlings thoroughly after planting.
- **Ensure any litter or waste is cleaned** up from the site after the planting activity is completed. Do not leave any plastic waste or containers or other behind.

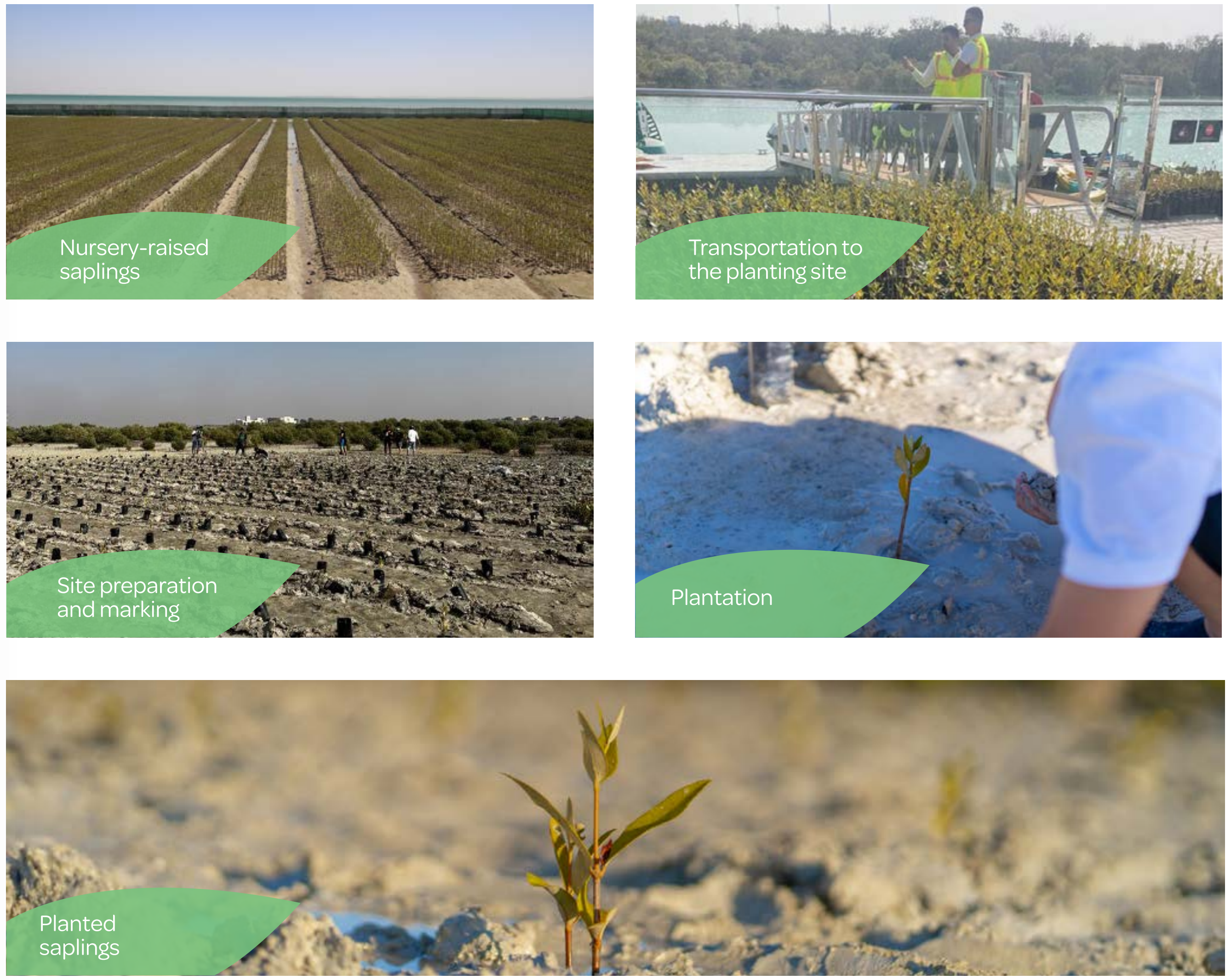


Figure 2.6: Planting of nursery raised saplings

2.5 PHASE 4: BASELINE AND MONITORING SURVEYS

Monitoring and evaluation activities should be carried out to assess the progress of the restoration project and make any necessary adjustments. This includes monitoring the growth and survival of the mangroves, as well as their ecological functions and the overall impact of the restoration on the local ecosystem. This can include measuring carbon sequestration and biodiversity.

The implementation of baseline and monitoring surveys is a valuable step in mangrove restoration. The surveys involve setting up designated monitoring plots within the identified restoration site to serve as key observation and data collection points.

The surveys include tracking the natural regeneration of mangroves, assessing the survival rates of planted trees, calculating important impact indicators, and wider impact of the restoration project. The monitoring methodology described in this section is based on the Tree Restoration Monitoring Framework developed by Conservation International and the technical guidance for mangrove planting developed by EAD. However, the methodology and indicators have been tailored to match the mangrove ecosystems of the UAE.

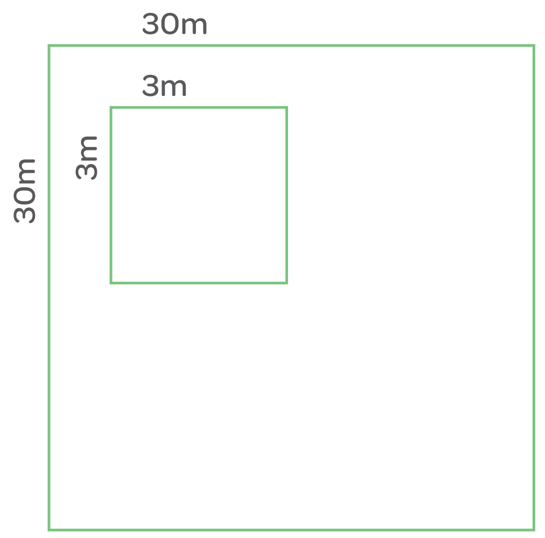
2.5.1 MONITORING PLOTS

To effectively monitor mangrove restoration areas, it is recommended to establish a series of monitoring plots.

The data collected from these plots at baseline will be pivotal in determining the total number of existing mangroves across the site. To ensure a representative sample, monitoring plots should be evenly distributed across the restoration area, avoiding any clustering, and be representative of the site where environmental conditions may impact the success of the mangroves. For example, sites with differences in soil types, elevation and species composition may be monitored separately to understand what attributes to an area's success (or failure). The location of the monitoring plots can be determined using GIS software or by dividing the restoration area into a grid, numbering each cell, and then using a random number generator to select plot locations.

The monitoring plots include setting up one main 30x30 meter plot per hectare, to monitor larger mangroves (height >= 130 cm). Within each of these plots, a smaller, nested 3x3 meter plot should be included. These nested plots are crucial for observing smaller mangroves (height < 130 cm) and for optionally monitoring biodiversity elements, such as gastropods and crabs, in addition to measuring soil characteristics.

The data collected from these monitoring plots will be used to extrapolate information for the entire restoration area. Therefore, it is crucial to ensure that these plots are representative and adequately cover the area. For monitoring sites with large scale seed dispersal by drone, monitoring should cover a sufficient area of not less than 10% of the total site and ensure adequate statistical representation.



For areas where drone seed dispersal has been carried out at large scale, it is recommended to have comprehensive mapping and field-based assessments pre-seeding and post-seeding, with a field-based monitoring area representing a minimum of 10% of each seeded site. Some drone seed dispersal projects have conducted monitoring through manual counting of an entire seeded area, by dividing the area into plots and sending trained teams of staff and volunteers to count and measure growth every 6 months. This intensive monitoring methodology is particularly necessary during drone dispersal trials, to adequately assess and quantify germination rates. In the near future, machine learning and ultra high-resolution imagery may facilitate faster and more efficient monitoring of large scale restoration initiatives involving seeding, however the level of accuracy needs to be verified before reporting success rates.

2.5.2 COMPREHENSIVE SURVEY (BASELINE) – PRE-RESTORATION

A comprehensive baseline survey establishes a reference for measuring progress by comparing conditions before and after restoration, necessary for assessing the project's success.

The survey can reveal site-specific details like soil properties, biodiversity, and mangrove health that may guide restoration efforts and support adaptive management, allowing for adjustments in response to challenges or opportunities.

Initial biodiversity assessments are key to understanding the site's ecological value and the potential benefits of restoration and show how restoration can positively impact the local ecosystem.

The collection of baseline data involves detailed recording of various aspects of the site, including:

- **Mangrove monitoring:** Information of the canopy area and height of existing surrounding mangroves.
- **Biodiversity surveys:** Assessments of existing fauna and flora help gauge the ecological health of the area and eventually help show the impact of the restoration on improving biodiversity. It is important to show this benefit across the coastal seascape including in saltmarshes, mudflats, and seagrasses. Examples include species and abundance of fish and birds, bats (using acoustic-based bat detectors), gastropods and crabs.
- **Soil and water characteristics:** Evaluating the soil and water conditions using field-based probes that measure pH, temperature, porewater salinity, and other characteristics, that influence mangrove growth can help evaluate successes and failures.
- **General site information:**
  - **Restoration type** (*e.g.*, planting, seeding, assisted natural regeneration, drone seeding)
  - **Data collection time**
  - **Plot details:** Information on plot size, type, strata, and tree planting patterns, geospatial data on monitoring locations, is the site adjacent to surrounding saltmarshes or seagrass
  - **Photos:** Photos of the site and in monitoring plots taken at the same location and view angle can demonstrate the progress over the project

A summary of the data elements is outlined in Table 2.10.

Table 2.10. Summary of Recommended Data Collection

Main Plot (30x30 m)	Sub Plot (3x3 m)	Optional: Whole Site
Large mangroves (divided into two classes: Height > 250 cm, 130-250 cm) • Count • Canopy width • Height	Small mangrove (Height < 130 cm): • Tree count • Health Status [Optional] Biodiversity [Optional] Soil/water characteristics • Interstitial salinity • pH • Conductivity • Temperature	Biodiversity • Species richness, composition, and diversity indexes. In mangroves, this may be: Bat species/ abundance Bird species/ abundance Fish species/ abundance

Control Area

Part of the baseline survey is also establishing and monitoring an undisturbed control area (10x10 m plot), to objectively evaluate restoration benefits. The current state of the potential area should be compared to a nearby reference site that provides a benchmark against the restoration performance.

This practice is designed around the Before-After Control-Impact (BACI) framework, which helps to clarify whether changes result from restoration efforts or external factors.

2.5.3 COMPREHENSIVE SURVEY (BASELINE SURVEY FOLLOW UPS) – YEARS 2.5, 5,10

In guiding the process of mangrove restoration, it is recommended to conduct comprehensive surveys, which are baseline survey follow ups at intervals of 2.5, 5, and 10 years following the initial restoration activities.

These surveys should mirror the baseline survey in methodology and scope, ensuring consistency in data collection and analysis. This includes general site information, plot details, vegetation assessments, photographic records, soil and environmental conditions, and biodiversity surveys. These periodic comprehensive surveys are integral to understanding the dynamic changes within the restored area and ensures that the restoration project remains responsive to the evolving needs of the mangrove ecosystem to maximise its ecological and environmental benefits.

2.5.4 SITE MANAGEMENT (QUARTERLY) – POST-RESTORATION

It is beneficial to consider conducting site management surveys as part of an adaptive management strategy. The primary purpose of these site management surveys is to assess the current status of restoration activities and identify any changes or disturbances at the site, which can be crucial for making timely adjustments.

A site management survey typically involves a brief site visit, during which observations are made and a limited set of data is collected from the established monitoring sub-plots (3 x 3 m). Site management surveys can be quarterly; however, the frequency will vary with the restoration method, anticipated environmental changes, or post-disturbance events, such as storms.

The data collection process is an integral part of ensuring the restoration project remains on track and is responsive to the evolving conditions of the site and can include the following parameters:

1. Seedling Health Status

Each mangrove within the 3x3 m plots (counted also in the baseline surveys) is classified for its health status using the classification:

- Healthy: Leaves green and clean of barnacles, <10% dead, yellowing or wilting leaves
- Sick: Yellow wilting leaves, low foliage cover, visible signs of disease, 10-50% dead, yellowing or wilting leaves
- Grazed: A small number of leaves are present but have noticeable bite marks, <50 % leaves, bite marks on remaining leaves
- Dead: Lesser to no leaves, most leaves are unhealthy, >50% dead yellowing or wilting leaves, >50% dead stems plant beyond recovery

2. Disturbances

A detailed record of any disturbances, whether natural (evidence of storms, floods, grazing) or human-induced (pest outbreaks, clearing, accidents). This can include the time, type, intensity, and extent of these events.

Based on the findings recorded from the seedling health status, adjustments may be required. Some adjustments to be considered are included below:

3. Adjustments

- **Protective Measures:** Install barriers or other protective structures to shield seedlings from grazing animals or harsh environmental elements like forceful waters that we have not identified during the site selection assessment. This helps in reducing physical damage to the young plants
- **Hydrological Adjustments:** Re-asses and modify the site's hydrology, if needed, to ensure optimal water flow and salinity levels, which are critical for mangrove survival
- **Replacement of Unsuccessful Seedlings:** Replace seedlings that have perished, provided their death was caused by factors unrelated to the site's natural progression, such as substandard seedling quality, incorrect planting methods, or external events like storms

By summarising mangrove health data from each monitoring plot, we can estimate the overall survival rate in the restoration area. This involves averaging the health status across all plots and calculating the average percentage survival of mangroves throughout the site.

2.5.5 REMOTE SENSING

For the first five years, field-based data collection is recommended (over remote sensing) to track the progress of restoration projects as smaller trees will not be visible via remote sensing.

Once the survival rate has stabilised and the canopy has become denser, remote sensing can be used to alongside traditional field surveys to speed up the monitoring process and expand the monitoring to the entire restoration area. Standardised GPS plot locations can be used to ensure a comparison between remote and field data. Satellite and drone data can also be calibrated against ground-truth field data for accuracy track mangrove health, coverage, and survival rates.

2.5.6 CITIZEN SCIENCE

Engaging local communities through citizen science not only enriches data collection but also fosters a deeper connection between the community and the mangrove ecosystem.

This engagement can include training sessions for community volunteers on data collection techniques and the importance of mangroves. Additionally, incorporating citizen science activities, such as mangrove health and biodiversity monitoring, can provide valuable data while enhancing public awareness and stewardship of the environment. Leveraging digital platforms such as iNaturalist can also help add to the data in the region.

2.5.7 UPLOADING BASELINE AND MONITORING DATA TO THE NATIONAL DATABASE

Baseline and monitoring data must be standardised and integrated into a national level database to enable the UAE to achieve its restoration goals and develop a better understanding of the factors affecting restoration success. An integrated platform for all restoration projects would ensure transparency and the sharing of information about restoration progress and status, allowing the restoration community to share lessons learnt and improving future restoration programs, as well as to benchmark against global programs, and ensure accurate and verifiable reporting about restoration programs and potential carbon sequestration benefits that result from these programs in the long term.

Figure 2.7 below indicates the monitoring framework and timeline around the restoration

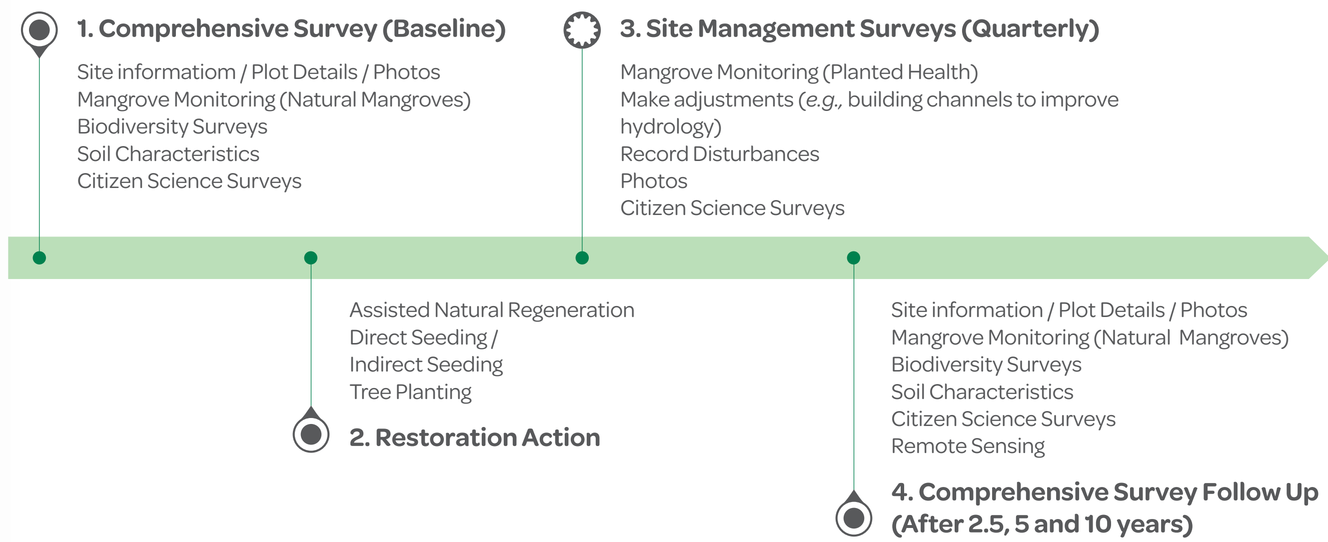


Figure 2.7 . Summary of Restoration and Monitoring Timelines

Table 2.11: Summary of key monitoring activities

Activity	Notes
Monitoring of restored sites	Restored areas to be plotted / divided to plots for monitoring for success rate. That will help in comparing the sites find reasons of low or high mortality. Monitoring can be conducted using both remote sensing and ground surveys, as well as drones and likely a combination of methods are needed depending on the site and the available resources
Monitoring of mangrove saplings	Random sampling of plants (height, number of healthy leaves in pair), density (number/m^2)
Survival rate of saplings	Count the number of seedlings surviving and workout the survival rate post summer and post winter (no of seedlings surviving/No of saplings/seeds planted X100) evaluate both the growth rate and survival rate to assess the success of the plantation
Mortality Rate and Reason for mortality	Identify the factors responsible for the failure of the plantation
Pest/ disease control	Pest/ disease attack can be noted in time and controlled
Record plastic / debris	Note the source of rubbish and steps taken to minimise the problem
Estimate replantation	Calculate and report number of saplings to be replanted as compensation to mortality
Future plan for monitoring	Advice if further monitoring required, if so, at what frequency

Summary: Monitoring Plan and Protection Measures

The failures of most restoration projects have been associated with lack of a monitoring plan. A monitoring plan for a mangrove restoration project should aim to track the progress of the restoration efforts and determine the success of the project. Assessment of the growth, survival, and health for the planted mangroves is important for a successful mangrove restoration program. It should be done by frequent observation and monitoring, including the identification of any potential pests or diseases that may impact the mangroves (See Table 2.12).

- **Determine the indicators:** determine the indicators that will be used to measure the success of the project. These could include regular monitoring of the mangroves to ensure they are healthy and thriving (measures of biomass, growth rate), diversity of the mangrove ecosystem, soil organic carbon, and water quality
- **Establish a baseline:** Before the restoration project begins, establish a baseline for the indicators that will be measured. This will provide a point of comparison for the progress of the project
- **Develop a monitoring schedule and science based monitoring protocol** aligned with best practice and that allows for statistical representation: The monitoring schedule should be established to track the indicators at regular intervals. This will allow for an assessment of progress and identify any areas that may need additional attention
- **Identify responsible parties:** Determine who will be responsible for collecting and analysing the data. This may include scientists (academia), project staff, volunteers, or contracted specialists
- **Analyse the data:** Analyse the data collected from the monitoring to assess the progress of the project. This will help identify areas that may need additional attention, and areas where the restoration efforts are having a positive impact

Table 2.12: Some common pests and diseases that can affect *Avicennia marina*

Caused by	Disease/ Symptom	Causative organism /species
Fungus	Stem canker/ branch dieback	*Cyphellophora sp.*
	Stem/branch canker	*Eutypella sp.*
	Branch dieback / stem canker	*Lasiodiplodia theobromae*
	Mortality	Oomycete
	Leaf spot	*Pseudocercospora avicenniae*
	Leaf Spot disease	*Aspergillus*
	White Leaf Spot disease	*Penicillium*
	Leaf Spot disease	*Pseudocercosporella*
	Brown Leaf Spot disease	*Rhizophus*
	Leaf loss Trunk rot Death	*Phytophthora sp*
Insects	Leaf spot, Die back	Caterpillar (sp. not mentioned)
	Stem cankers/ Die back	Wood-boring beetles
	flat leaf-galls	**Midge fly** (*Cecidomyiidae*)
	Canker, die-back and stem/ branch bleeding	**Ambrosia beetles** *Euwallacea xanthopus Xyleborinus aemulus Xyleborus perforans*
	Severe defoliation	*Nephopteryx syntaractis*
	Seedling size reduction	*Cenoloba obliteralis*
	Seedling size reduction	*Euphranta marina*
	Leaves damaged	*Pablia species*
	Defoliation	*Hyblaea puera*

3

FINAL RECOMMENDATIONS AND FUTURE RESEARCH

Mangrove restoration projects must consider the restoration needs of the site and align them with science-based restoration targets. Funders of restoration projects must take into account the long-term investment and commitment required for successful verifiable mangrove restoration projects. Setting restoration targets solely as number of planted trees may not result in benefits to local communities and may not support a net gain of biodiversity or enhance resilience to climate change. Taking the time to plan a restoration project effectively, review best practice, mobilise the needed ecological expertise, assess the site through baseline surveys and understand the history and future land use of the site will help in setting realistic targets and proposing interventions that result in a net biodiversity gain, and enhancing the role of mangroves as powerful nature-based solutions to climate change. The sharing of lessons learnt and outcomes from restoration projects across the UAE, the region and worldwide will improve our knowledge on successful restoration interventions and practices, and this can only be done with systematic documentation of restoration projects, standardised monitoring where possible and regular data sharing. It is recommended that data from all restoration projects in the UAE is integrated into a shared database to enable continued research on how to improve mangrove ecosystem restoration.

Future research needs for the UAE should focus on the biophysical parameters affecting growth, refining criteria for site selection for restoration, developing innovative and cost-effective restoration and post restoration monitoring techniques using technology and artificial intelligence, studying the variability in carbon sequestration in restored sites, and developing effective methods of hydrological restoration, amongst others. These future research needs are outlined in more detail in Table 3.1 below.

Table 3.1 Identified priority research needs for mangrove ecosystems in the UAE

Topic	Required Research
Carbon Sequestration Studies	Studying the variability in carbon sequestration in restored site but also over the lifespan of mangroves. This necessitates determining average tree lifespans, time to maturity, and the impact of environmental conditions on growth
Factors affecting growth	Identifying factors influencing survival rates, including key variables affecting growth across different life stages and impact of restoration techniques
Reproduction studies	Assessing reproductive age and seed and clarifying when mangroves begin producing seeds and quantity produced
Health indicators	Identifying indicator species of a healthy mangrove ecosystem and developing cost-effective monitoring methods are vital for assessing restoration progress and biodiversity variations
Biodiversity assessments	Assessing the biotic communities within mangrove ecosystems in restored Vs natural areas and the progression or net gain in biodiversity over time in successfully restored areas

Finally, any restoration program would be incomplete without including a long-term monitoring and conservation plan for the site and adjacent associated habitats. Advocating for and supporting the establishment of the needed regulatory and socio-economic framework for the conservation of existing natural habitats and for the long-term protection of the restored site is essential to ensure that restoration efforts do not go in vain.

ANNEXES

ANNEX - A:
UAE Mangrove Restoration Case Study

Site Selection, Restoration and Monitoring Surveys

Introduction

Emirates Nature-WWF started working on a project in 2021 to regenerate mangrove ecosystems and associated coastal ecosystems while creating a platform for stakeholder and community engagement, expert collaboration, and civil society participation. The project includes two years of restoration, followed by a year of adjustments and modifications, and four years of monitoring.

This case study details our mangrove restoration project in Umm Al Quwain Lagoon, emphasising our ecosystem-based site selection criteria and long-term monitoring activities.

1.Site Selection

Stage 1: Identifying Broad Potential Restoration Areas

Following the Conservation International (CI) science-based best practices, we applied a comprehensive site selection strategy that considered economic, social, environmental, and political factors to ensure long-term success and biodiversity. Khor Al Yeefrah was identified as a suitable site for restoration through a two-stage evaluation process using the following criteria (Table A.1).

Table A.1. Criteria for Site Selection

Presence of a control site: Control sites, areas left with no intervention, serve as a baseline for gauging the impact of restoration interventions by allowing comparisons with 'business as usual' scenarios	**Long-term security in land tenure:** Essential to ensure areas are prevented from urbanisation and development and planting can occur legally. Commitment is critical from the long-term success of the project
Promote 'additionality' and avoid 'leakage': Ensuring that interventions lead to tangible benefits beyond what would naturally occur, while avoiding the displacement of emissions or deforestation or unintentionally create incentives for deforestation	**Promote important biodiversity:** Sites with ecological significance were prioritised to maintain, recover or expand. Determined through Ramsar sites, Important Bird Areas, key biodiversity areas and through local knowledge
Degraded (for more than 10 years): To avoid any potential perception of incentivising deforestation with recent land-clearing, the restoration project focuses on areas that have been degraded prior to 2010	**Ecosystem connectivity:** Ecosystem connectivity is associated with diverse benefits and biodiversity (Barbier, 2018; Pittman *et al.,* 2021). Sites were prioritised to enhance connectivity amongst habitats
Canopy cover less than 10%: The selected site had less than 10% canopy cover for at least 10 years. This ensures an alignment with voluntary market protocols	**Accessible:** Site is easily accessible by foot for greater community engagement with minimal disruption to local wildlife
Promote community engagement: Areas accessible to the community which bring societal benefits and a sense of ownership	**Avoid critical habitats:** Surrounding critical habitats should be assessed for their ecological significance and avoided when necessary

Based on the criteria, Khor Al Yeefrah was identified as an optimal site for mangrove restoration. The area has been ecologically degraded since before 2010, with less than 10% canopy cover, aligning it with the criteria and eliminating the risk of restoring recently cleared lands. The area is part of the UAQ lagoon, which is a key biodiversity area (KBA Partnership, 2023) and is part of a complex seascape of interconnected habitats in Umm Al Quwain lagoon (Mateos-Molina *et al.*, 2020) The restoration is expected to enhance biodiversity and contribute to ecosystem connectivity. The results from the steps described above are summarised in Table A.2.

Table A.2. Simplified example of site selection matrix

Site	Emirate	PPC Criteria				Emirates Nature - WWF Criteria					
		Degraded +10 yr	Canopy Cover % (2011)	Canopy Cover % (2021)	Control Site	Ramsar	Important Bird Area	Grading Needed?	No. of Habitats within 500m	Easily Accessible	Approximate Restorable Size (Ha)*
Umm Al Quwain 3 *	UAQ	Yes	2	10	Yes	No	Yes	No	6	Yes	45
Umm Al Quwain 4 *	UAQ	Yes	2	8	Yes	No	Yes	No	6	May be	27
Umm Al Quwain 1 *	UAQ	Yes	5	5	Yes	No	Yes	Yes	4	No (need boat)	11.6
Umm Al Quwain 2 *	UAQ	Yes	5	5	Yes	No	Yes	Yes	4	No (need boat)	14
Umm Al Quwain 5 *	UAQ	Yes	10	60	Yes	No	Yes	No	5	May be	6.9

* Site visited   * Potential for restoration   * Not possible under the PCC criteria or need elevation to be graded

Note: Some criteria follow more detailed guidelines even though they are classified as "yes/no" in the table above. This table is a simplified version of the matrix used.

Stage 2:
Refining sites within Khor Al Yeefrah - Field-Based Assessment

During site visits, we conducted in-depth assessments of existing ecology and previous plantings to evaluate their suitability for mangrove restoration. Guided by recommendations for daily inundation times between 180 and 450 minutes (Erftemeijer and Yamamoto, 2021), tidal data was collected over three days using the Nautide app, where tidal coefficients were near 70 to represent typical water levels. This data, along with key environmental factors such as tidal patterns, elevation, soil quality, and vegetation density, allowed us to delineate two distinct areas that met all criteria for successful mangrove growth.

2. Baseline Survey

We conducted a formal assessment of the existing conditions at the two identified sites to establish a baseline understanding of the area's natural features, such as trees, species, and biodiversity. This baseline data will serve as a reference point for evaluating the impact of project-related changes on the area.

To characterise each restoration site, we established multiple permanent sample plots sized proportionally to the area being restored. Following the guidelines from the CI vegetation monitoring framework, we set up one 30x30m plot per hectare for documenting larger mangroves and added four 1x1m sub-plots randomly positioned within each main plot to capture data on smaller mangroves and indicator species. This data will be used to determine the number of mangroves and carbon sequestered across the site. A survey workbook was developed to collect the data elements shown in Table A.3.

Table A.3. Baseline survey collected data

30x30 m plot	1x1 m sub-plot
• Large mangrove tree count (divided into three classes: > 250 cm, 130-250 cm, and <130 cm) • Large mangrove tree canopy width • Large mangrove tree height	• Small mangrove tree count (<130 cm) • Gastropod trail count • Crab burrow count • Soil characteristics (interstitial salinity, pH, conductivity, and temperature)

Photos of each corner in the 30x30m plot and north-facing photos of each 1x1m subplot were taken for future comparisons. A site-wide count of large mangroves was performed, excluding canopy and height details. A bat detector (Song Meter SM4BAT FS) was also deployed for a week on a mangrove tree to assess bat species and population density.

Figure A.1. EN-WWF team conducting baseline surveys at UAQ

3. Community Mangrove Restoration

In March 2023, a collaborative effort involving the UAQ community, and Emirates Nature-WWF's Leaders of Change program resulted in the planting of 14,000 mangrove seedlings. Participants were informed on the benefits of mangrove restoration and how mangroves contribute to ecosystem services. Healthy seedlings, sourced from a local UAQ nursery, averaged 30 cm in height and were carefully transported each morning, held from the bottom to prevent stem damage. To optimise growth potential while minimising nutrient competition and disturbances, planting activities were strategically timed during low tide and employed a zig-zag layout with one-metre spacing between seedlings. This design, informed by previous restoration efforts of *Avicennia marina* (Erftemeijer and Yamamoto 2021; Erftemeijer *et al.,* 2017), strikes a balance between high seedling density and minimal competition, while also accounting for existing vegetation, pneumatophores, and crab holes.

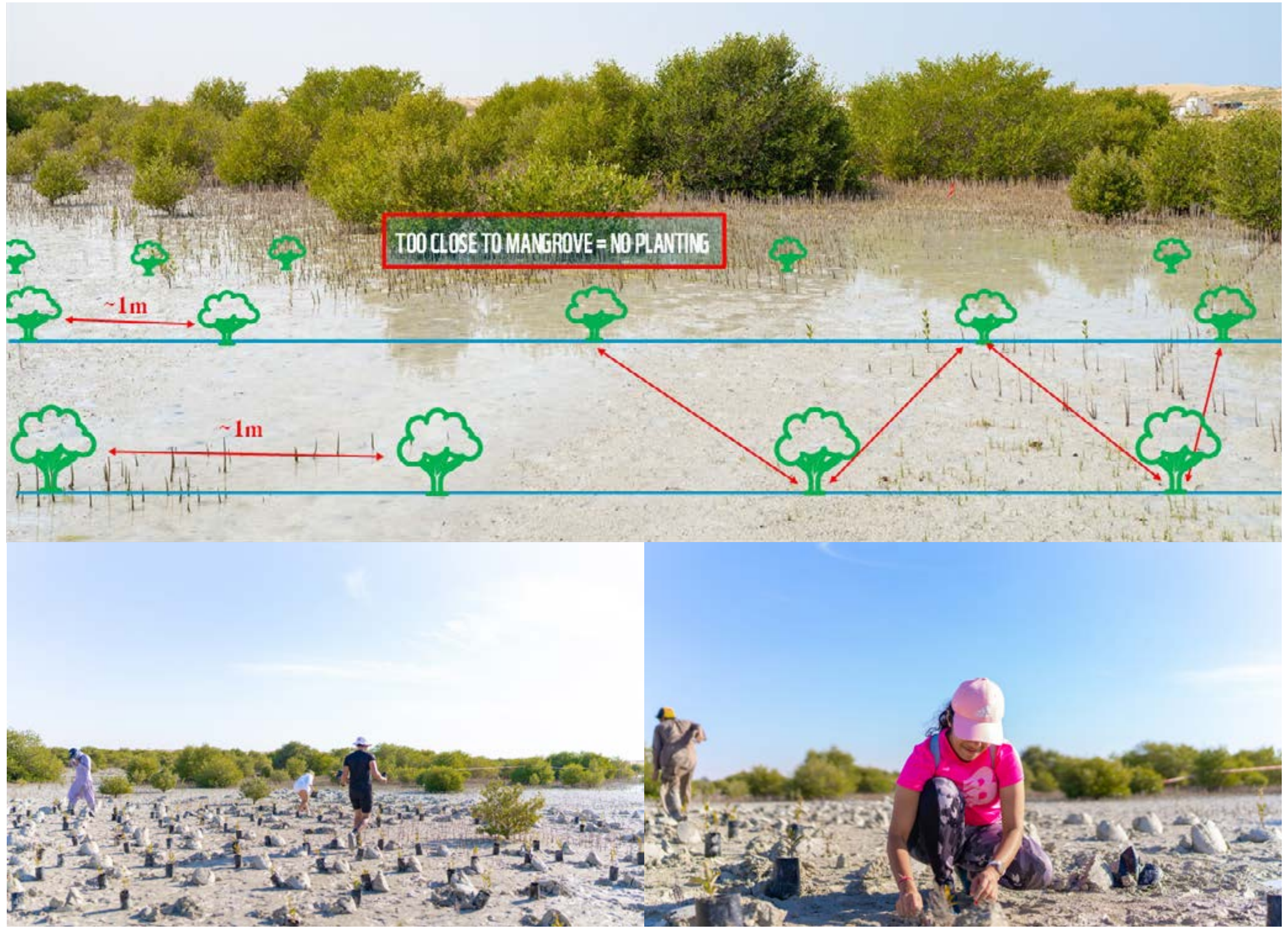


Figure A.2. Mangrove planting at UAQ

4. Monitoring

The monitoring process was divided into two procedures; a regular monitoring of the state of the site, and a long-term monitoring to understand the evaluating the impact of project-related changes on the area.

Regular monitoring was conducted to adaptively manage the newly planted mangroves, inform long-term ecosystem sustainability, and identify any failures and potential causes. The monitoring schedule was phased: weekly checks for the first four weeks, monthly for the next five months, and bi-monthly thereafter. Elements of the monitoring include:

- Seedling count per subplot
- % survived seedlings
- Height/canopy width of seedlings
- Health of seedlings (classified as 'healthy', 'sick', 'dead', 'grazed')

Long-term monitoring follows the monitoring framework developed by CI and WRI with the aim of assessing project impact, enable adaptive management, and maximise the scientific contributions. This framework applies best practices and advanced technology, using standardised metrics and procedures. We will conduct comprehensive surveys at critical milestones—Year 2.5 and Year 5 post-planting—to gauge vegetation establishment and growth. These surveys will include factors assessed in the baseline survey (see Section 3), such as mangrove growth and biodiversity, as well as soil characteristics like interstitial salinity, pH, conductivity, and temperature.

Initial results from short-term monitoring undertaken 5 months after planting indicates a 96% survival rate of seedling.

Figure A.3. Snapshots from monitoring activities at UAQ

5. Challenges and Lessons Learned

This section includes some challenges and lessons learned from the project.

- Translocation causes temporary stress on the mangrove seedlings, evident as yellowing of leaves as they acclimate to new soil and tidal conditions. Despite concerns about the health of the seedlings, they returned to green and healthy after 21 days
- High clay-content in the soils can extend the area hospitable to mangroves. In UAQ, some areas were not inundated daily, clay-dominated soils appear to be enhancing the seedling survival by retaining water between high tides
- High resolution topographic data that can be used to evaluate inundation times and mapping boundaries suitable for mangroves, was challenging to source. Manual estimates using tidal coefficients and field surveys have so far succeeded in achieving high survival rates of seedlings in the upper intertidal zones
- Efforts should focus on reducing plastic waste from seedlings transported in plastic bags, where possible, which generated waste that is potentially recyclable

ANNEX - B: Inundation Time Methodology

Table B.1. Methods to Assess Inundation Times

Method	Description	Benefit	Challenge	Cost
High resolution satellite data (<5 m spatial resolution)	Analyse satellite imagery over time to observe tidal patterns and water coverage. Use image timestamps to calculate the duration of inundation.	High accuracy in mapping and monitoring tidal patterns over large areas.	May not capture short-term or subtle tidal changes. Dependent on satellite pass times and weather conditions.	Medium to high
Drone-based data	Use drone imagery to map the extent of tidal inundation. Compare images taken at different tides to estimate inundation time.	Provides detailed, localised data on tidal influence and inundation patterns.	Limited by drone flight time and weather conditions. Requires skilled operation and analysis.	Medium
Ground-based techniques	Consult local tide gauge records, focusing on a tidal coefficient of 50% to represent average tidal range. Conduct between 2 and 3 site visits at high and low tides, recording GPS coordinates of these extremes to map tidal influence accurately. Then, draw lines between these coordinates to mark high and low water levels, defining the area typically inundated by tides. Estimate average inundation time based on these lines, assuming a uniform slope and the standard tidal cycle duration of approximately 6 hours and 12 minutes. Finally, use the area between these lines, the inundation band, to set mangrove restoration boundaries, ensuring alignment with essential tidal influences for successful mangrove growth.	Medium to low accuracy in determining exact inundation times but provides a practical, on-the-ground assessment.	Time-consuming and labour-intensive, requiring multiple site visits and manual data collection. It may also be less accurate in areas with complex or rapidly changing tidal patterns.	Low

ANNEX - C: Mudflats

Mudflats are often areas identified for mangrove restoration. As such, a careful assessment of each area is essential to prevent mudflats habitat from being destroyed given that they are important areas for waterbirds[1].

To assess a site's importance for waterbirds, one should first look for key ecological indicators: This involves surveying the mudflat for a high density of invertebrates, such as molluscs and crustaceans. The presence of these organisms, often evidenced by trails left in the mud (as depicted in Figure C.1), contribute to a number of important ecosystem functions such as food to support fish and birds and nutrient and carbon cycles[2]. Well-connected mudflats, close to other coastal habitats such as mangroves, saltmarshes and seagrass, are likely to support a higher diversity and density of fish[3].

Figure C.1. Mudflats surrounding dense mangrove forests are likely to be important areas for waterbirds.

[1] Campbell, O., 2023. An Introduction to the Birds of the United Arab Emirates. In A Natural History of the Emirates (pp. 469-505). Cham: Springer Nature Switzerland.

[2] Dissanayake, N.G., Frid, C.L., Drylie, T.P. and Caswell, B.A., 2018. Ecological functioning of mudflats: global analysis reveals both regional differences and widespread conservation of functioning. Marine Ecology Progress Series, 604, pp.1-20.

[3] Meijer, K.J., El-Hacen, E.H.M., Govers, L.L., Lavaleye, M., Piersma, T. and Olff, H., 2021. Mangrove-mudflat connectivity shapes benthic communities in a tropical intertidal system. Ecological Indicators, 130, p.108030.

ANNEX - D: Soil and Water Conditions

Numerous conditions can be assessed at the restoration site to identify potential reasons for the lack of natural regeneration, or to find new areas for mangrove habitats.

Table D.1 provides an overview of key parameters essential for the growth of *Avicennia marina* in the UAE. It includes optimal ranges for each parameter, methods for measurement, and interventions to enhance survival rates, drawing on insights from past restoration projects.

Additional factors include those on water quality (such as Salinity, pH, and Dissolved Oxygen) and soil quality (including pH, porewater salinity, nutrients like Nitrogen, Phosphorus, and Potassium, redox potential, sulphide levels, and organic matter content), but there is a lack of research on optimal thresholds for *Avicennia marina* growth in the region.

Table D.1. Summary of Biophysical Characteristics for Optimal *Avicennia marina* Growth

Parameter	Importance	Justification	Approximate Range	How to Determine	Possible Intervention
Soil Characteristics					
Type and Texture (Sandy, Silt, Loam, Clay)	High	Determines water retention and aeration and affects root penetration and water movement	Muddy/silty substrates that are spongy to well-drained, organic-rich soils	Soil texture feel test[1] or jar test[1]	Soil amendments, drainage. In hard soils: Raking, peat moss addition [2]
Soil Quality					
pH	Medium	Influences nutrient solubility and microbial activity	Neutral pH[3]	Soil pH testing kits, soil probes.	Modify hydrology to increase water circulation, excavated channels should have time to neutralise (~4 months)[4]
Porewater Salinity	Medium	Affects soil structure and plant water uptake	32 – 78 ppt [5]	Refractometer	Modify hydrology to increase water circulation

[1] Stewart M, Fairfull S. Mangroves. Profitable and sustainable primary industries. PRIMEFACT. 2008;746:9–10. https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6706e/x6706e06.htmchrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://extension.unl.edu/statewide/lincolnmcpherson/Soil%20Texture%20Analysis%20%E2%80%9CThe%20Jar%20Test%E2%80%9D.pdf

[2] Erftemeijer, P., Ito, S. and Yamamoto, H., 2021. Creating mangrove habitat for shoreline protection: Working with Nature in the Arabian Gulf. Terra et Aqua, 162, pp.16-27.

[3] Erftemeijer, P., Ito, S. and Yamamoto, H., 2021. Creating mangrove habitat for shoreline protection: Working with Nature in the Arabian Gulf. Terra et Aqua, 162, pp.16-27.

[4] Erftemeijer, P., Ito, S. and Yamamoto, H., 2021. Creating mangrove habitat for shoreline protection: Working with Nature in the Arabian Gulf. Terra et Aqua, 162, pp.16-27.

[5] Findings from the Priceless Planet Coalition project with Emirates Nature- WWF, funded by Mastercard.

References

Abd-El Monsef,H. Ayman S.H. Aguib, Scot E. Smith. Locating suitable mangrove plantation sites along the Saudi Arabia Red Sea Coast. Journal of African Earth Sciences 83(2013) 1-9.

Aspinall, S., Böer, B., Ziolkowski, M., Hogarth, P. and Beech, M., (2002). Biosphere Reserve Study, Sharjah, UAE.

Alsumaiti, Tareefa S, Khalid Hussein, and Ameena Saad Al-Sumaiti. 2017. "Mangroves of Abu Dhabi Emirate, UAE, in a global context: a review." International Journal of Environmental Sciences 6 (4):110-121.

Balke, Thorsten, Tjeerd J Bouma, Erik M Horstman, Edward L Webb, Paul LA Erftemeijer, and Peter MJ Herman. 2011. "Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats." Marine Ecology Progress Series 440:1-9.

Barbier E. B. (2018). "Seascape Economics: Valuing Ecosystem Services Across the Seascape," in Seascape Ecology, 1st Edition. Ed. Pittman S. J. (Hoboken, New Jersey:Wiley).

Beeston, M., Cameron, C., Hagger, V., Howard, J., Lovelock, C., Sippo, J., Tonneijk, F., van Bijsterveldt, C. and van Eijk, P. (Editors) 2023. Best practice guidelines for mangrove restoration.

Carpenter, S., Evans, C., Pittman, S.J., Antonopoulou, M., Bejarano, I., Das, H.S., Möller, M., Peel, K., Samara, F., Stamoulis, K.A. and Mateos-Molina, D., 2023. Multi-habitat carbon stock assessments to inform nature-based solutions for coastal seascapes in arid regions. Frontiers in Marine Science, 10.

EAD (2015). Technical Guidance Document for Mangrove Planting Permitting and Management Plan (EAD-TMBS-TG-01 (Rev No.1).

Ellison, J.C., 2015. Vulnerability assessment of mangroves to climate change and sea-level rise impacts. Wetlands Ecology and Management, 23, pp.115-137.

Ellison, J.C. 2009. Geomorphology and Sedimentology of Mangroves. p. 565-591. In: Perillo, E. Wolanski, E. Cahoon, D.R. and Brinson, M. (eds.), Coastal Wetlands: An Integrated Ecosystem Approach, Elsevier, Amsterdam. ISBN 978-0-444-53103-2.

Elmahdy SI and Ali TA. 2022. "Monitoring changes and soil characterization in mangrove forests of the United Arab Emirates using the canonical correlation forest model by multitemporal of landsat data". Front. Remote Sens. 3:782869. doi: 10.3389/frsen.2022.782869.

Erftemeijer, Paul LA, Titus Agastian, Hiroshi Yamamoto, Marion L Cambridge, Roderik Hoekstra, Geoff Toms, *et al.*, 2020. "Mangrove planting on dredged material: three decades of nature-based coastal defence along a causeway in the Arabian Gulf." Marine and Freshwater Research 71 (9):1062-1072.

Erftemeijer, Paul LA, Marion L Cambridge, Brae A Price, Satoshi Ito, Hiroshi Yamamoto, Titus Agastian, *et al.*, 2021. "Enhancing growth of mangrove seedlings in the environmentally extreme Arabian Gulf using treated sewage sludge." Marine Pollution Bulletin 170:112595.

Erftemeijer, Paul LA, and Robin R Lewis In. 2000. "Planting Mangroves on Intertidal Mudflats: Habitat Restoration or Habitat Conversion?" Proceedings of the ECOTONE VIII Seminar "Enhancing Coastal Ecosystems Restoration for the 213i Century, Ranong, Thailand. Royal Forest Department of Thailand, Bangkok, Thailand.

Erftemeijer, Paul LA, Satoshi Ito, and Hiroshi Yamamoto. 2021. "Creating mangrove habitat for shoreline protection. Working with nature in the Arabian Gulf." Terra et Aqua (162 Spring 2021).

Erftemeijer, Paul LA, Brae A Price, Satoshi Ito, Hiroshi Yamamoto, Titus Agastian, and Marion L Cambridge. 2021. "Salvaging and replanting 300 mangrove trees and saplings in the arid Arabian Gulf." Marine and Freshwater Research 72 (11):1577-1587.

Erftemeijer, Paul LA, Nicole Wylie, and Garnet J Hooper. 2017. "Successful mangrove establishment along an artificially created tidal creek at Port Hedland, Western Australia." Marine and Freshwater Research 69 (1):134-143.

Erftemeijer, P., Ito, S. and Yamamoto, H., 2021. Creating mangrove habitat for shoreline protection: Working with Nature in the Arabian Gulf. Terra et Aqua, 162, pp.16-27.

Farnsworth E. 2000. The ecology and physiology of viviparous and recalcitrant seeds. Ann Revue Ecol Systematics 31:107-38

Fickert, T., 2020. To plant or not to plant, that is the question: Reforestation vs. natural regeneration of hurricane-disturbed mangrove forests in Guanaja (Honduras). Forests, 11(10), p.1068

Friess, D.A. 2016. J.G. Watson, Inundation Classes, and their Influence on Paradigms in Mangrove Forest Ecology. Wetlands 37(4): 603-613

Friis G, Killilea, M.E, Mangrove Ecosystems of the United Arab Emirates (2024) in J. A. Burt (ed.), A Natural History of the Emirates, https://doi.org/10.1007/978-3-031-37397-8_7

Friis G, Burt JA (2020) Evolution of mangrove research in an extreme environment: historical trends and future opportunities in Arabia. Ocean Coast Manag 195:105288. https://doi.org/10. 1016/j.ocecoaman.2020.105288

Friis G, Vizueta J, Smith EG, Nelson DR, Khraiwesh B, Qudeimat E *et al.,* (2021) A high-quality genome assembly and annotation of the gray mangrove, Avicennia marina. G3 11(1):jkaa025. https://doi.org/10.1093/g3journal/jkaa025

Friis G, Smith EG, Lovelock CE, Ortega A, Marshell A, Duarte CM, Burt JA (2022) Isolation in cryptic glacial refugia and extreme environmental conditions drive rapid lineage diversification in Arabian gray mangroves. Authorea. https://doi.org/10.22541/au.165451878.80994363/v3

Gatt YM, Andradi-Brown DA, Ahmadia GN, Martin PA, Sutherland WJ, Spalding MD, Donnison A and Worthington TA. 2022. "Quantifying the reporting, coverage and consistency of key indicators in mangrove restoration projects". Front. For. Glob. Change 5:720394. doi: 10.3389/ffgc.2022.720394.

Ghasemi, S., Zakaria, M. and Mola Hoveizeh, N., (2011). Abundance of molluscs (Gastropods) at mangrove forests of Iran. Journal of American Science, 7(1), pp.660-669.

Jacob Solomon Raju Aluri. A Review of the Reproductive Ecology of Mangrove Plant Species.2022. In book: Mangroves: Biodiversity, Livelihoods and Conservation. DOI: 10.1007/978-981-19-0519-3_3

Duke, N.C., A.H.B. John, J.A. Goodall & E.R. Ballment (1998). A genetic structure and evolution of species in the mangrove genus Avicennia (Avicenniaceae) in the Indo-west pacific. Evolution 52: 1612–1626

Luri Nurlaila Syahid, Anjar Dimara Sakti, Riantini Virtriana, Ketut Wikantika, Wiwin Windupranata, Satoshi Tsuyuki, Rezzy Eko Caraka and Rudhi Pribadi. (2020). Determining Optimal Location for Mangrove Planting Using Remote Sensing and Climate Model Projection in Southeast Asia. Remote Sensing.

Kairo, J.G., Mangora, M.M., Network, W.I.O.M. and Western Indian Ocean Marine Science Association, 2020. Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region-Western Indian Ocean Ecosystem Guidelines and Toolkits

Kabir, M., Abolfathi, M., Hajimoradloo, A., Zahedi, S., Kathiresan, K. and Goli, S., (2014). Effect of mangroves on distribution, diversity and abundance of molluscs in mangrove ecosystem: a review. Aquaculture, Aquarium, Conservation & Legislation, 7(4), pp.286-300.

Maher,D.T.,Santos,I.R.,Golsby-smith,L.,Gleeson,J.,and Eyre,B.D.(2013).Groundwater-derived dissolved inorganic and organic carbon exports from a mangrove tidal creek: The missing mangrove carbon sink? Limnology and Oceanography, 58(2), pp. 475-488.

Marchand, L., Castagneyrol, B., Jiménez, J.J., Benayas, J.M.R., Benot, M.L., Martínez-Ruiz, C., Alday, J.G., Jaunatre, R., Dutoit, T., Buisson, E. and Mench, M., 2021. Conceptual and methodological issues in estimating the success of ecological restoration. Ecological Indicators, 123, p.107362.

Mateos-Molina, D., Antonopoulou, M., Baldwin, R., Bejarano, I., Burt, J.A., García-Charton, J.A., Al-Ghais, S.M., Walgamage, J. and Taylor, O.J., 2020. Applying an integrated approach to coastal marine habitat mapping in the north-western United Arab Emirates. Marine Environmental Research, 161, p.105095.

McDonald, T., Gann, G., Jonson, J., and Dixon, K. (2016). International standards for the practice of ecological restoration–including principles and key concepts. (Society for Ecological Restoration: Washington, DC, USA.). Soil-Tec, Inc., © Marcel Huijser, Bethanie Walder

Moore, G.E., Grizzle, R.E. and K.M. Ward. 2013. "Mangrove resources of the United Arab Emirates: Mapping and site survey 2011-2013". Final Report to the United Arab Emirates Ministry of Environment and Water. 28pp.

Oh, R. R. Y., Friess, D. A., and Brown, B. M. (2017). The role of surface elevation in the rehabilitation of abandoned aquaculture ponds to mangrove forests, Sulawesi, Indonesia. Ecological Engineering 100, pp. 325-334. . 475-488.

Omer Mohamed Yousif and Sumitro Sen. Reintroduction of red mangrove Rhizophora mucronata in Abu Dhabi Emirate, United Arab Emirates. World Journal of Advanced Research and Reviews, 2020, 07(02), 210–217

Pittman S. J., Yates K. L., Bouchet P. J., Alvarez-Berastegui D., Andréfouët S., Bell S. S., *et al.,* (2021). Seascape Ecology: Identifying Research Priorities for an Emerging Ocean Sustainability Science. Mar. Ecol. Prog. Ser. 663, 1–29. doi: 10.3354/meps13661

Quattrocchi U. 2000. CRC World Dictionary of Plant Names. 1 A-C, Boca Raton: CRC Press. p. 242.

Roy R Lewis 2005. Mangrove Restoration - Costs and Benefits of Successful Ecological Restoration. FAO

Samara, Fatin, Nadia Solovieva, Thouraya Ghalayini, Zaina Anwar Nasrallah, and Maria Saburova. 2020. "Assessment of the Environmental Status of the Mangrove Ecosystem in the United Arab Emirates" Water 12, no. 6: 1623. https://doi.org/10.3390/w12061623.

Saengera, P. Blascob,F. Loughland.R and A. Youssef. The mangrove resources of the UAE with particular emphasis on those of the Abu-Dhabi Emirate.2004

Saenger, P. 2003. Mangrove Ecology, Silviculture and Conservation. Kluwer Academic Publishers, Dordrecht, The Netherlands, 360 pp

Sprenkle-Hyppolite, Starry & Alexandre, Nikola & Begeladze, Salome & Brandt, John & Cross, Jamie & DeWitt, Sean & Hillman, Isabel & Martin, Ornanong & Metzel, Ruth Ngolela & Minnick, Aaron & Stolle, Fred & Woldemariam, Tesfay. (2023). Tree Restoration Monitoring Framework: Field Test Edition

Teutli-Hernández C., J.A. Herrera-Silveira, D.J. Cisneros-de la Cruz., R. Román-Cuesta. 2020. "Mangrove ecological restoration guide: Lessons learned. Mainstreaming Wetlands into the Climate Agenda: A multi-level approach (SWAMP)". CIFOR/CINVESTAV-IPN/UNAM-Sisal/PMC, 42p.

Tomlinson PB. 1986. The botany of mangroves. New York (US): Press Syndicate of the University of Cambridge. 419 p.

UNEP-Nairobi Convention/USAID/WIOMSA. 2020. "Guidelines on Mangrove Ecosystem Restoration for the Western Indian Ocean Region". UNEP, Nairobi, 71 pp. A digital copy of this report is available at: www.nairobiconvention.org; www.wiomn.org; www.wiomsa.org.

Wilson S.J., Harrigan E. *et al.,* 2022. Where to restore? Using Spatial Data to Inform Restoration Prioritization for Climate, Biodiversity and Community Benefits. Conservation International.

Further Reading (Knowledge Resources Links)

Global Mangrove Alliance Best Practice Guidelines
https://www.mangrovealliance.org/best-practice-guidelines-for-mangrove-restoration/

International principles and standards for the practice of ecological restoration (second edition)
https://onlinelibrary.wiley.com/doi/10.1111/rec.13035

Guidelines for ecological restoration, including socioeconomic components, establishing goals in the planning phases.
https://doi.org/10.1038/s41559-019-0942-y

An introduction to decision science for conservation
https://doi.org/10.1111/cobi.13868

Mangrove restoration under shifted baselines and future uncertainty
https://doi.org/10.3389/fmars.2021.799543

Getting it right, a guide to improve inclusion in multistakeholder forums
https://www.cifor.org/knowledge/publication/7973/

IUCN Legal Frameworks for Mangrove Governance
https://portals.iucn.org/library/node/48361

USAID LandLinks Tools and Guides repository
https://www.land-links.org/tools-and-missionresources/tools-and-guides/

Mangrove restoration: To plant or not to plant
https://www.wetlands.org/case-study/mangrove-restoration-to-plant-or-not-to-plant/

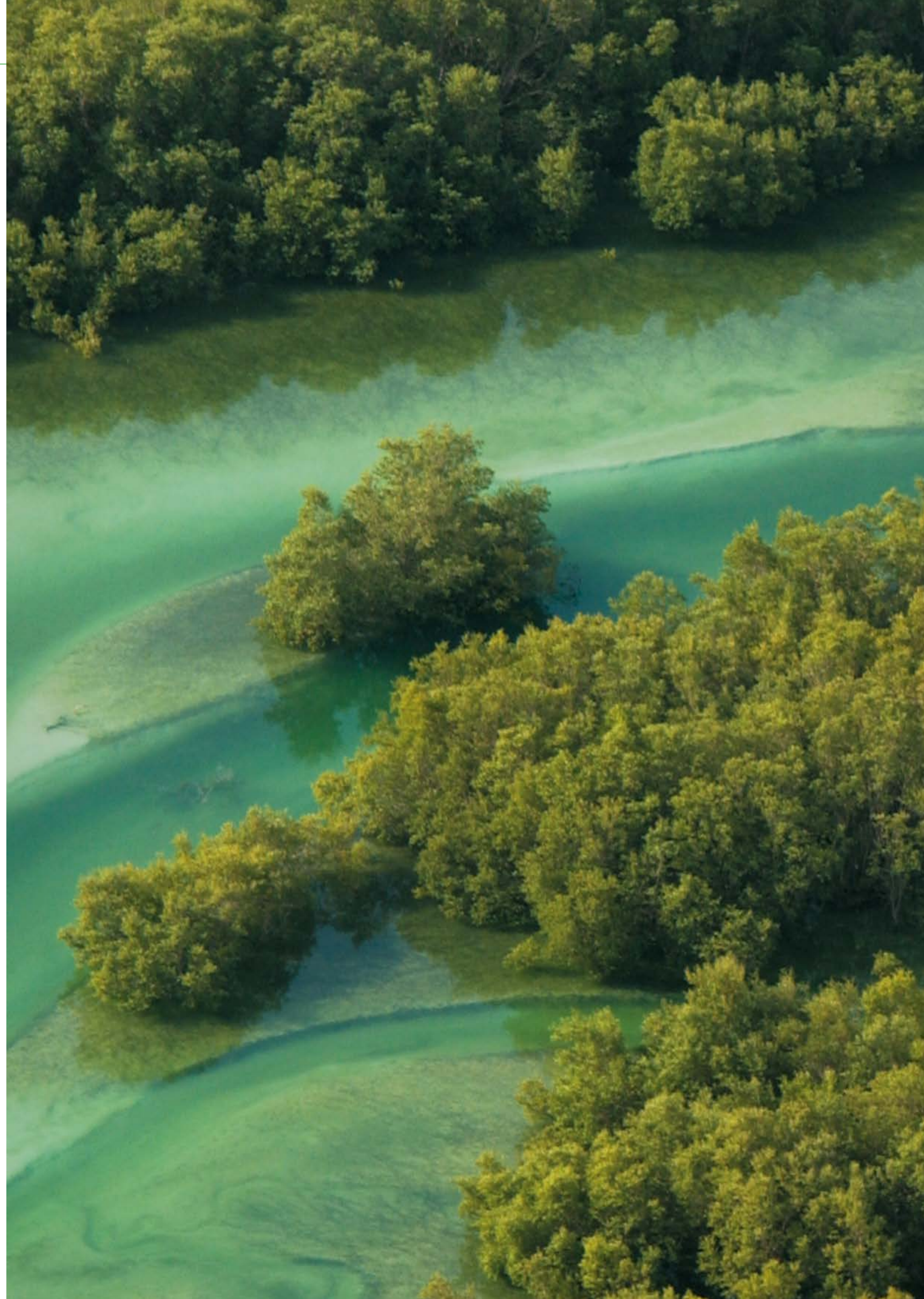
The Best Practice Guidelines for Mangrove Restoration
https://www.mangrovealliance.org/wp-content/uploads/2023/12/Best-Practice-Guidelines-for-Mangrove-Restoration_spreadsv5.pdf

Mangrove Law and Policy November 2023
https://www.mangrovealliance.org/wp-content/uploads/2023/12/GMA-Policy-Brief_V6.pdf

Guiding Principles - The Mangrove Breakthrough
https://www.mangrovealliance.org/wp-content/uploads/2023/04/Mangrove-Breakthrough-Guiding-Principles.pdf

The Global Mangrove Watch
https://www.globalmangrovewatch.org/

GMA – Our 2030 Goals
https://www.mangrovealliance.org/wp-content/uploads/2024/01/GMA_Our-2030-Goals_ENGLISH.pdf



نحافظ على تراثنا الطبيعي . ضماناً لمستقبلنا
preserving our heritage · protecting our future

ص ب 45553 . أبوظبي . الإمارات العربية المتحدة
PO Box 45553 · Abu Dhabi · United Arab Emirates

T +971 2 693 4444 هـ

customerhappiness@ead.gov.ae
www.ead.gov.ae

FSC