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Institute of Marine Affairs 45th Anniversary

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MARIN TOBAGO

MARINE RESILIENCE INITIATIVE

A Guide to Coral Reef and Seagrass Restoration in Tobago

Version 1

Anjani Ganase, Attish Kanhai, Hannah Lochan, Nikia Gooding

Institute of Marine Affairs

September 2023

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Problem Statement

Marine ecosystems of Tobago have suffered a long history of loss and degradation owing to a number of acute disturbance events with little recovery to date. Over the last 50 years, Caribbean reefs including Tobago's reefs have been degraded by a number of disease outbreaks, thermal stress events and chronically unhealthy environmental conditions (Laydoo 1984; O'Farrell and Day 2005; O'Farrell and Day 2006; Harding et al. 2008; Mallela and Parkinson 2008; Hassanali 2009, Mallela and Crabbe 2009; Lapointe et al. 2010a; Mallela et al. 2010; Alemu and Clement 2011; Buglass et al. 2016; Alemu and Mallela 2021). Evidence of coral loss is well documented on Tobago's coral reefs with a decline of ~ 50 % of hard coral populations since 2010 (largely as a result of 2010 mass bleaching event) with minimal recovery to date (Ganase 2020). Furthermore, geographic location as the most southern Caribbean reef system, and the influence of the Orinoco outflow and the Guiana current renders position Tobago in isolation with limited Coral larvae replenishment from neighbouring islands (Schill et al. 2015).

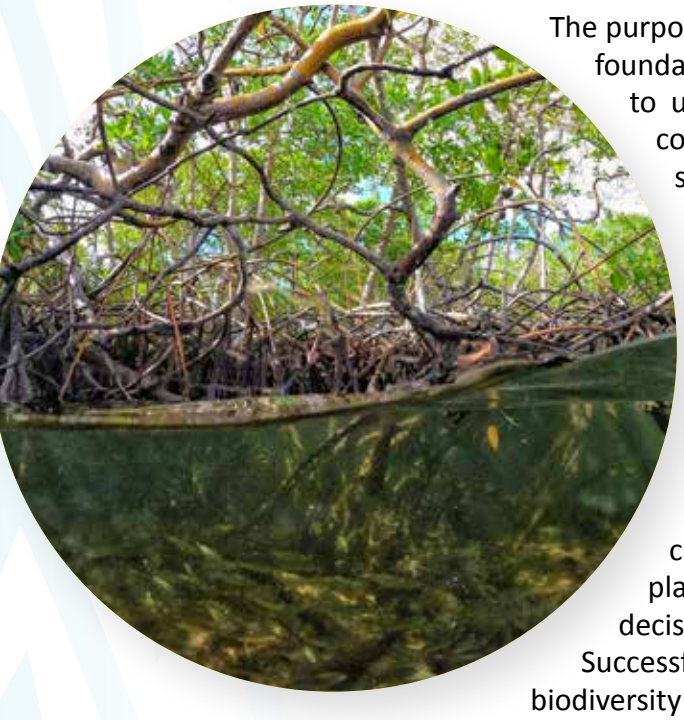
Seagrasses in Tobago have suffered a similar fate as large tracts have been lost over the last 20 years because of coastal development and land-based sources of pollution. The chronic influx of sedimentation and nutrient pollution smothers seagrass beds and stifles recovery. Seagrass communities in southwest Tobago, in particular, have been subjected to anthropogenic impacts in the form of nutrient enrichment from sewage effluent as evidenced by historical data collected by the Institute of Marine Affairs (Juman, 2004). While less is known about the status of seagrasses in northeast Tobago, there are reports of seagrass loss in Speyside, Charlotteville and King's Bay (Pers. Comms. 2022).

Considering our dependency on marine ecosystems to provide critical services in the form of food security, coastal protection, and livelihoods, there is an urgent need to ramp up management interventions to include strategies for restoration. Climate projections reveal up to 99 % of coral populations will be lost with a two-degree temperature rise by 2050 (IPCC Special Report 1.5 (Masson-Delmotte et al. 2018). Much of the loss will be associated with the increase in the number of warming events, and disease outbreaks, and global models project that Tobago's reefs are likely to experience annual severe bleaching between 2046 (RCP 8.5 scenario) and 2064 (RCP 4.5 scenario) (Maynard et al. 2015; van Hooidonk et al. 2015). This gives just over twenty years to work towards building ecosystem resilience through management and restoration intervention. This is not a lot of time, considering that recovery associated with restoration can only be definitively measured after ten years (Jaap 2000; Abrina and Bennett 2018, 2021).

Coral bleaching at Speyside, 2010 Mass Coral Bleaching Event
photo courtesy Jonathan Gomez

Degrading environmental conditions were identified as a key issue threatening the health of seagrass meadows throughout the Caribbean with numerous stressors (van Tussenbroek et al. 2014). The seagrass communities within the Bon Accord Lagoon, Tobago have been subjected to anthropogenic impacts in the form of nutrient enrichment from sewage effluent, as well as direct removal (Juman 2004; Ramoutar and Persad 2018) and resulted in a decline in seagrass productivity and biomass.

Purpose of this report



Mangroves of Bon Accord Lagoon subjected to pollution. Photo courtesy Anjani Ganase

The purpose of the Marine Resilience Initiative pilot study is to build foundational knowledge and resource capabilities to be able to utilise restoration as an effective tool for managing and conserving Tobago's marine ecosystems (coral reefs and seagrasses) against disturbances. More specifically, the pilot reviews existing literature in restoration planning and design for seagrass and coral reefs and investigates specific applications for Tobago that would inform the essential steps for conducting restoration in Tobago. The output is the first compilation of results into a first version (V1.0) of a guide to marine ecosystem (coral reef and seagrass) restoration in Tobago that sits within a resilience-based management framework (a management framework focussed on dealing with future uncertainty of climate change). The overarching goal of the guide for restoration planning and design is for cohesive and knowledge-based decision-making in management and restoration in Tobago. Successful implementation aims to achieve conservation of marine biodiversity and maintenance of ecological functions, as well as building resilience against climate change. In turn, healthy and resilient ecosystem services will continue to serve the livelihoods of Tobagonians. Continued research and testing of restoration strategies will inform future versions of the guide, as a working document, in an iterative process.

Pilot Objectives

Coral reef component

1. Conduct a literature review of coral reef restoration planning, design and implementation
2. Assess the current ecological state of five pilot coral reefs in Tobago to determine resilience and vulnerability for management/ restoration prioritisation
3. Record patterns of coral spawning and recruitment on Tobago's coral reefs to guide the intended coral larvae propagation restoration strategies
4. Introduce stakeholders to the concept of coral reef restoration and garner interest for conducting specific activities, such as coral spawning observations that are aligned with eco-tourism.

Seagrass component

1. To map the seagrasses of Bon Accord Lagoon to identify suitable donor sites.
2. To conduct an ecological assessment of seagrass beds in Bon Accord Lagoon
3. To estimate the carbon stored in the seagrass beds of Bon Accord Lagoon
4. To trial different methodologies for suitability at select replanted sites
5. To build community engagement during the seagrass replanting process

Introducing Tobago's coral reefs and seagrasses

Historical context

Caribbean coral reefs

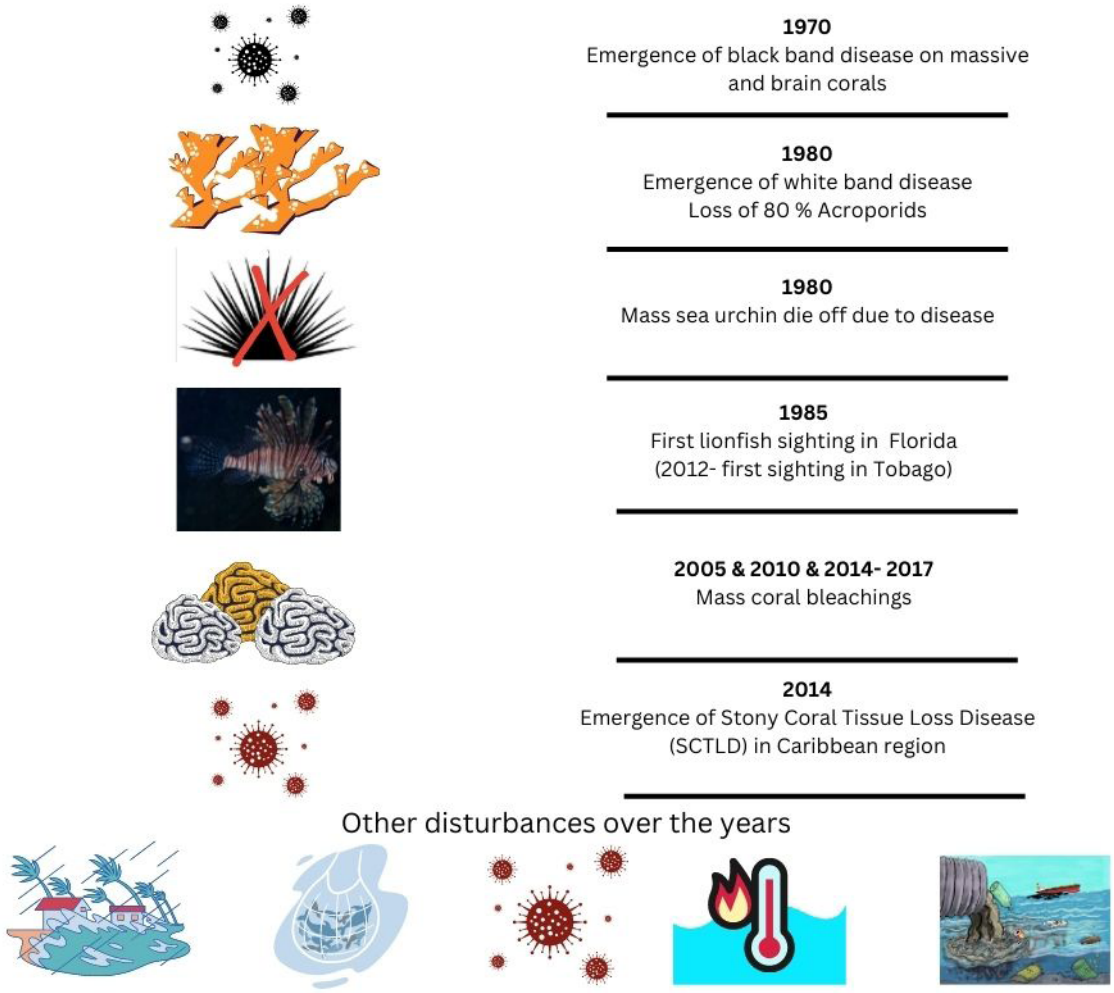
Coral reefs contribute to a myriad of ecosystem services including coastal protection, sources of food, habitat, and nursery areas for marine life (Smith 1978; Done 1999; Moberg and Folke 1999; Woodhead et al. 2019). However, since the 1970s, coral reefs have been impacted by a number of disturbances and suffered declines in coral populations and health throughout the Caribbean (Figure 1). Continued proliferation of land-based sources of pollution, overfishing and disease outbreaks, aggravated by climate-related disturbances, such as ocean warming, and extreme storm events have resulted in mass coral mortality (Hughes et al. 2003; Pandolfi et al. 2003; Harborne et al. 2017). Caribbean reefs have shifted to alternative stable states with non-reef builders (octocorals, fleshy macroalgae, sponges) dominating, in place of the habitat providing hard corals. Continued coral loss (< 10 % cover) will result in a transition from a positive reef building state to net erosion of reef structure and habitat loss (Perry et al. 2013).

Mt. Irvine Reef
Photo courtesy Jonathan Gomez

Tobago's coral reefs

Developed coral reefs fringe much of the southwest, northeast Tobago and Caribbean coast (Figure 2). The Institute of Marine Affairs (IMA) has been conducting research on Tobago's coral reefs since the 1980s. Since the establishment of IMA's long-term coral reef monitoring programme in 2010, there has been a decline in hard coral cover by 50 % across most monitoring sites, largely from the 2010 coral bleaching event (Figure 3). Today, Tobago's reefs have coral cover that averages ~ 15 % (Ganase 2020; Alemu I and Mallela 2021) (Figure 3). The limited recovery of hard coral cover on Tobago's reefs (and many Caribbean reefs) is attributed to poor recruitment of corals because of unsuitable conditions for coral settlement and survival driven by pollution (nutrient and sedimentation) and overfishing of herbivores that clean surfaces of macroalgae to facilitate coral recruitment (Hughes and Tanner 2000). Caribbean reefs, including Tobago, have undergone transitions in recruitment from key reef-building species to weedy species that do not provide long-term reef infrastructure (Buglass et al. 2016; Cramer et al. 2021). While Tobago's coral cover has not seen any further declines since 2010, the paucity of new generations of reef-building corals is a major concern for the future.

Figure 1 Timeline of disturbance events for Caribbean coral reefs, consisting of disease outbreaks, thermal stress events, along with a highlight on other issues including hurricanes, overfishing, increased disease, rising sea temperatures and pollution (Hughes and Jackson 1985; Hughes 1994; Goreau et al. 1998; Aronson and Precht 2001; Donner et al. 2007; Eakin et al. 2010; Alemu I and Clement 2014; Alvarez-Filip et al. 2022) Images © Canva



In 2006, reef-related tourism, fisheries and coastal protection were estimated to be valued at USD ~140 million dollars for Tobago (Burke et al. 2008). Reef degradation across the Caribbean accounts for an estimated revenue loss of ~ US $350 million to US $870 million per year for declines in fisheries production (30 - 45 % projected loss from 2000 - 2015), reef-related tourism (scuba diving: 1 - 10 % projected loss from 2000 - 2015) and coastal protection (projected loss 2000 - 2050) (Burke and Maidens 2004). While data on such loss in valued services is limited for Tobago, monitoring has revealed declines in commercial fish species since the 1990s (Institute of Marine Affairs 2000), and coastal erosion within the Buccoo Reef Marine Park and along other coastal areas in southwest Tobago (Smith Warner 2022).

While management is needed, progress is slow. Buccoo Reef was designated a restricted area under the Marine Area (Preservation & Enhancement) Act of 1970, yet to date there has been little progress in the implementation of a management plan. In 2005, the Buccoo Reef along with the surrounding Bon Accord Lagoon and fringing mangroves were declared a Wetland of International Importance

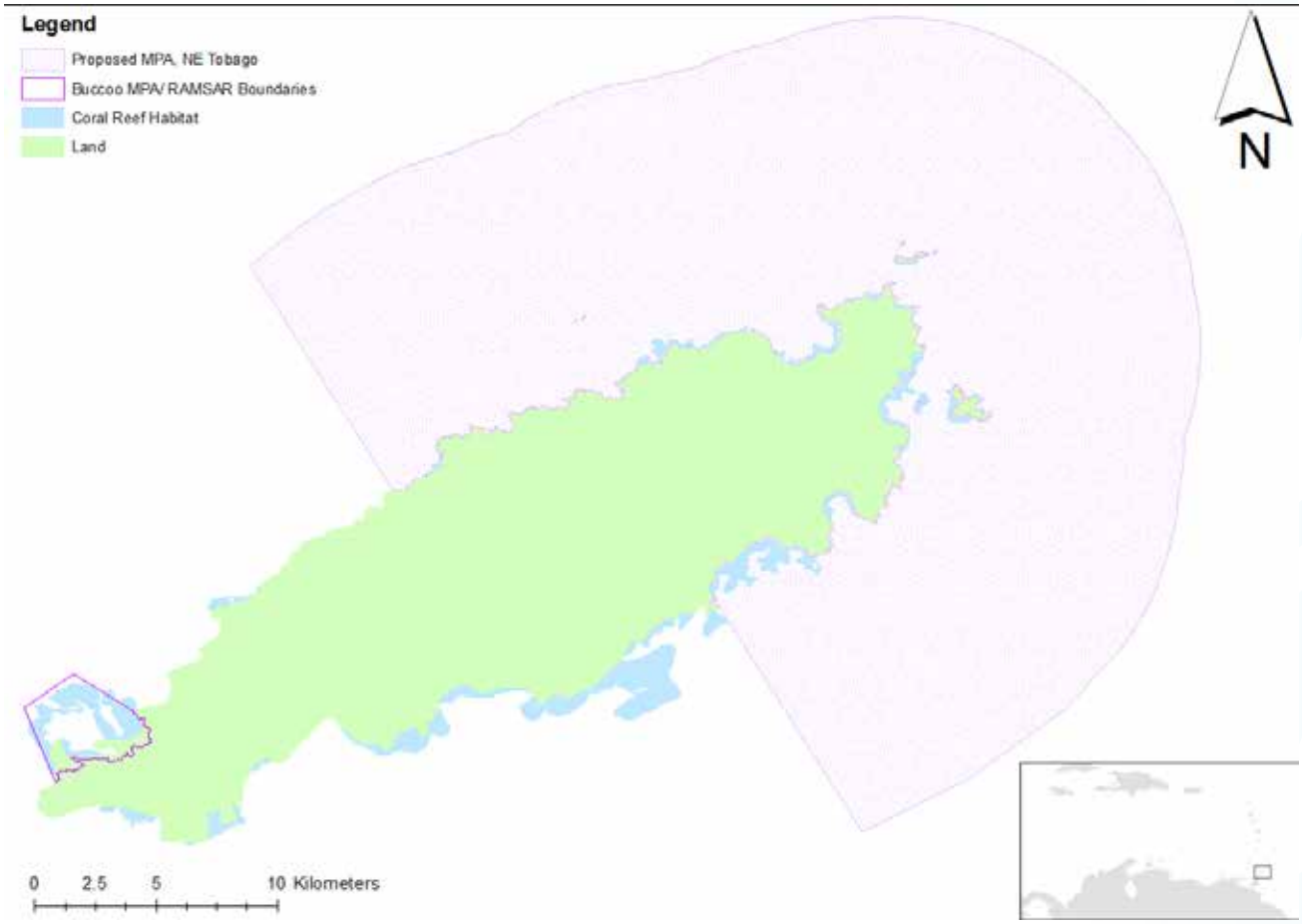


Figure 2 Distribution of coral reef habitats around Tobago and the demarcation of (1) Buccoo Reef Marine Park and RAMSAR wetland, (2) proposed marine protected area for north-east Tobago

(RAMSAR Site) due to its significant biodiversity and ecological importance as a nursery habitat. For north-east Tobago, the UNESCO Man and Biosphere Reserve (MBR) was designated in 2020, as the largest in the English-speaking Caribbean with intact Ridge-to-Ocean ecosystems (UNESCO 2020). The area encompasses many coastal and marine environments, including coral reefs, offshore islands and pelagic ecosystems. The marine area within the reserve is proposed as a Marine Protected Area (MPA) and a management plan is being drafted. Previous iterations of proposed marine management have been done for Speyside during the 1990s (IMA 2000).

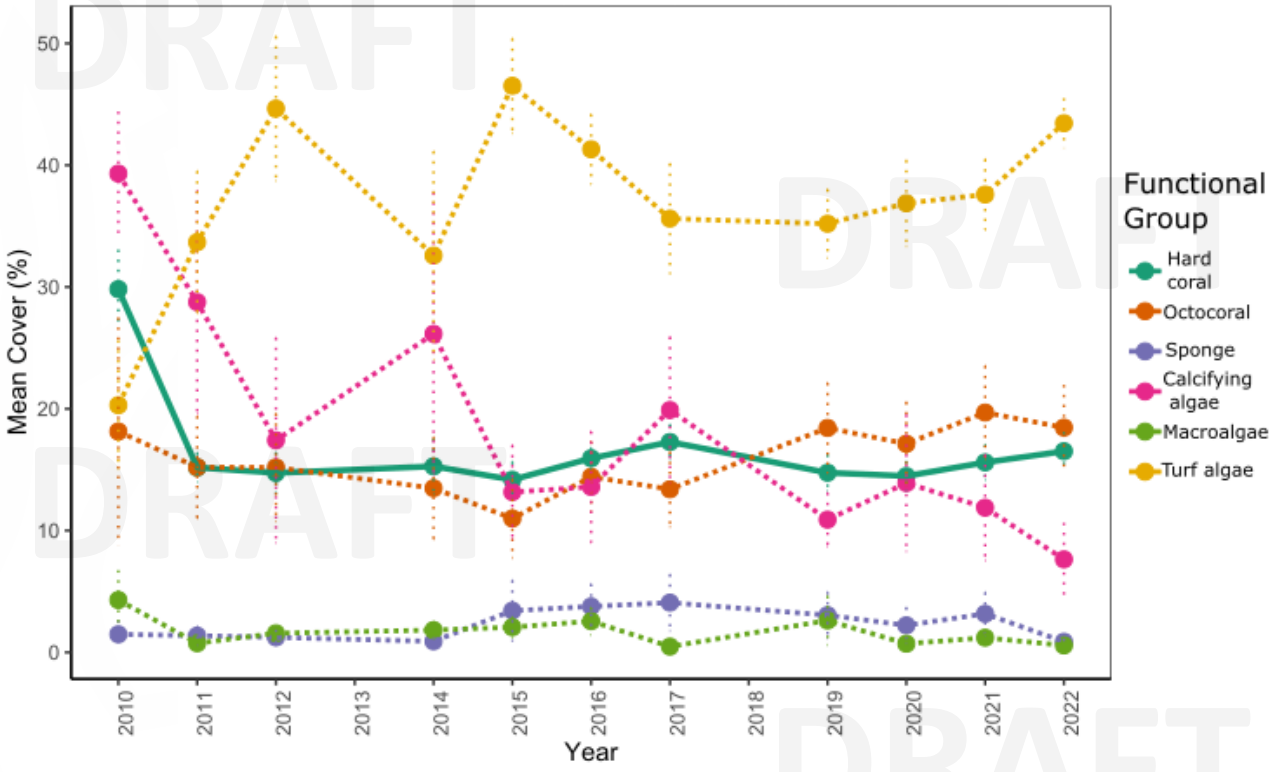


Figure 3 Changes in hard coral cover averaged across IMA's long-term monitoring sites from 2010 (4 sites) to 2022 (10 sites).

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Climate change and Tobago's coral reefs

According to the IPCC Special Report, coral reefs are projected to decline a further 70 - 90 % with a 1.5 °C global temperature rise, while a 2° C rise will result in 99 % loss (Masson-Delmotte et al. 2018). In 2022, global warming is at 1.2° C (Climate Action Tracker 2022). Warming oceans lead to coral bleaching events that result in mass coral mortality. While Tobago's reefs have suffered major coral loss from the 2005 and 2010 coral bleaching (O'Farrell and Day 2006; Alemu I and Clement 2014), more recently, reefs continue to be impacted with minor bleaching events being reported annually since 2019 (Plate 1; Pers. Comms.). While bleaching at these scales may impact certain species, locations and depth, it continues to erode the existing coral populations. El Niño weather patterns drive warmer oceanic conditions in the southern Caribbean and is associated with severe coral bleaching events (1998, 2010 and 2015/ 2016 bleaching events) (Claar et al. 2018). However, global warming conditions are revealed by observations of bleaching even under La Niña conditions (McGowan and Theobald 2023). This year, 2023, is predicted to experience El Niño weather conditions (TT Meteorological Office). Warming events also drive coral disease outbreaks (Bruno et al. 2007). Following the 2005 bleaching event, dark spot disease and yellow-band disease became prevalent on Tobago's reef (Mallela and Parkinson 2008; Hassanali 2009). White-band disease, associated with the mass die-off of 80–98% of Caribbean Acroporids (Kline and Vollmer 2011), is likely to be attributed from ocean warming (Randall and van Woesik 2015). Bleaching frequency for Tobago is expected to worsen with severe bleaching events expected annually by mid-century (van Hooidonk et al. 2015, 2016).

Plate 1 Bleached coral in 2022.
Photo credit: Hannah Lochan.

Seagrass beds

Ecological function and ecosystem services

Seagrass ecosystems are highly productive, faunally rich and an ecologically important marine resource. They provide ecosystem services and benefits that greatly contribute to healthy oceans, fisheries, and livelihoods of coastal communities (Duarte et al. 2013; Ondiviela et al. 2014; Unsworth et al. 2019). These ecosystems are associated with sheltered marine or brackish bays and estuaries, and are often connected to mangrove and coral reefs in lagoons between the coastlines and the

coral reefs (van Tussenbroek et al. 2014). Seagrasses provide habitat structure. Many epiphytes grow on the blades of the grass, including algae, diatoms and bacterial films that serve as a food source at the base of the food chain which are then grazed on by large fauna, such as green turtles, parrotfish, surgeonfish, and sea urchins and shrimp (Zieman 1982). Seagrass habitats also serve as a nursery and residential grounds to many commercial fish and shellfish species, such as tarpon, snapper, grunts, shrimp, crab and lobster (Robblee et al. 1991; Nagelkerken et al. 2001; Unsworth et al. 2019). Other important ecosystem services include habitat connectivity with adjacent marine ecosystems (mangrove and coral reefs), nutrient cycling and filtration (Heck et al. 2008), coastal protection and supporting livelihoods in tourism. Seagrasses are sites of significant carbon sinks, and the conservation of seagrasses can play a major role in climate change mitigation (Gullström et al. 2018).

The dominant species found in the Caribbean and Tobago is turtle grass (*Thalassia testudinum*), which is widely distributed in the tropical Atlantic from Venezuela to Cape Canaveral in Florida and also in Bermuda (Juman et al. 2006). Turtle grass is possibly the most important marine spermatophyte – seed bearing plant - along the coasts of the Caribbean and Gulf of Mexico (Den Hartog 1970). The species grows from the low-water mark down to 10 m in clear water. Establishment occurs on a wide variety of substrates, including organic matter, rocky matter, coral sand, and dead reef-platforms (Juman et al. 2006).

Seagrass of the Nylon Pool, Tobago.
Photo courtesy Anjani Ganase

History of disturbance

Numerous large-scale declines of seagrass meadows spanning wide geographical ranges have been reported in recent decades with most of this loss being due to human activities, (Orth et al. 2006; Waycott et al. 2009; Green et al. 2021; Dunic et al., 2021) (Figure 4). Large die-offs of turtle grass *(Thalassia testudinum)* have been well documented and eutrophication from fertiliser use on large-scale agricultural lands has been theorised as the main cause of seagrass decline worldwide (Orth et al. 2006).

Chronic impacts to Caribbean seagrass meadows are no different from the global context, however seagrass decline is exacerbated by the additional threat of acute extreme weather events (van Tussenbroek et al. 2014). Furthermore, alterations of beach habitats and activities to support tourism place seagrasses under considerable pressure. Coastal development, including the installation of in-water structures, such as jetties and moorings, dredging, and reclamation result in habitat loss. Damage associated with commercial exploitation of coastal resources have also negatively impacted seagrass communities. Sediment runoff from land clearing activities for agriculture and construction, and coastal developmental smothers seagrasses resulting in mortality. Activities such as boating, anchoring, fishing and other recreational activities potentially result in the fragmentation of seagrass meadows (Short and Wyllie-Echeverria 1996; Orth et al. 2006; Waycott et al. 2009; van Tussenbroek et al. 2014).

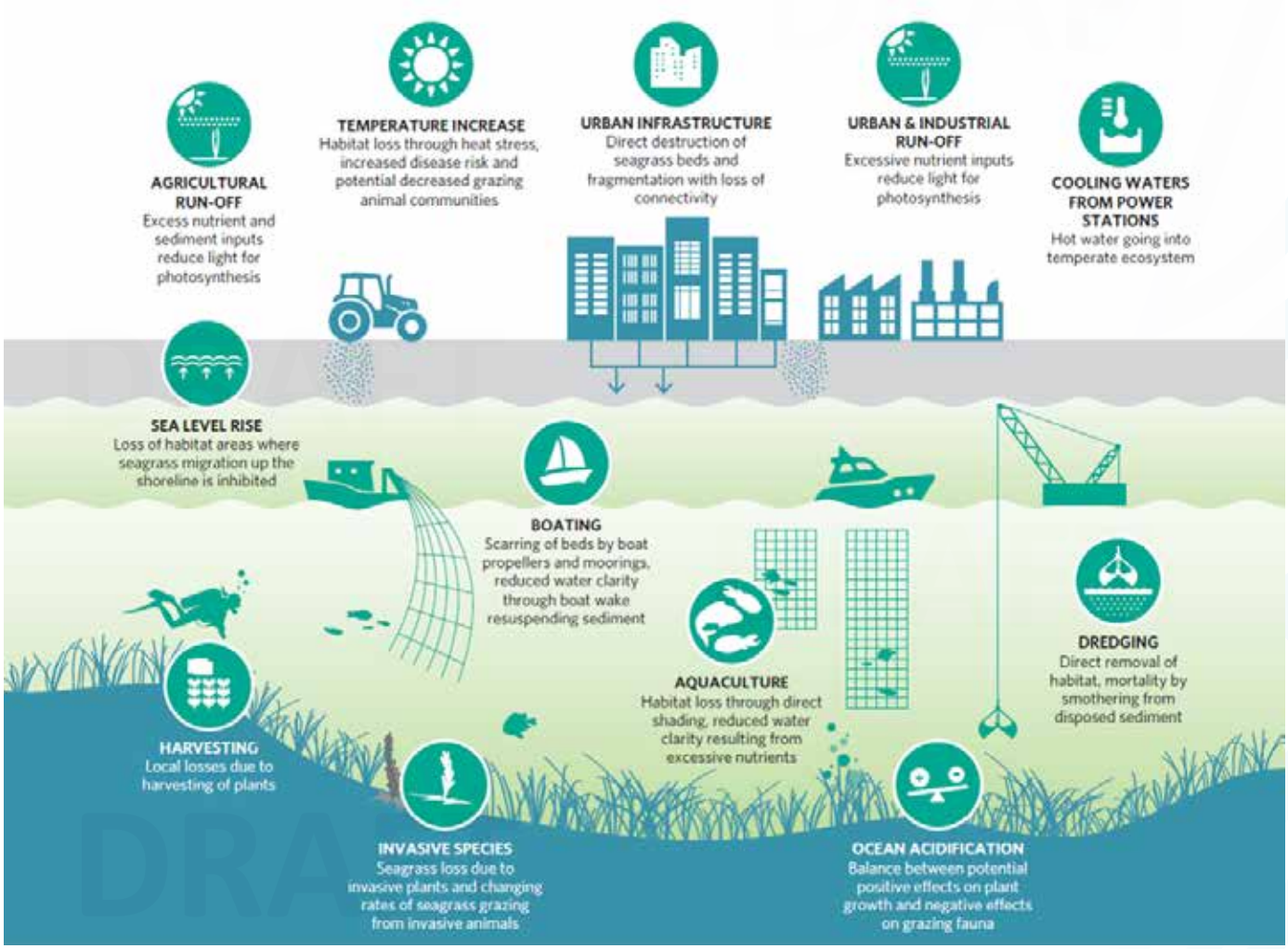


Figure 4 Major threats to seagrass habitats. Image sourced from Gamble et al., 2021. Seagrass Restoration Handbook. Zoological Society of London, UK., London, UK: https://catchmentbasedapproach.org/wp-content/uploads/2021/10/ZSL00168-Seagrass-Restoration-Handbook_20211108.pdf

Bon Accord Lagoon – Buccoo Reef Complex

Seagrasses are found mainly in south-west Tobago with the largest expanse of *Thalassia* dominated seagrass bed being found in Bon Accord Lagoon. In 2000, seagrass meadows in the Bon Accord Lagoon were estimated to cover 54.3 ha and this almost doubled to approximately 102 ha in 2010 (Juman 2004; IMA, 2010). The increase in seagrass coverage can be attributed to an increase in colonised areas as well as improvements in technology used to map the spatial distribution of these habitats. Today, seagrass beds of south-west Tobago continue to be the most expansive on the island (Figure 5). While turtle grass *(Thalassia testudinum)* is the dominant species, other seagrass species are found interspersed in the area including shoal grass (*Halodule wrightii*) and Caribbean seagrass or paddle grass (*Halophila decipiens*) (Juman 2004). This area contributes to the mangrove-seagrass-coral reef continuum with the Buccoo area (Juman 2004).

In the early 2000s, dense *Thalassia* beds also covered the south-western area of Buccoo Bay towards Sheerbird's Point covering 100 m to 300 m seaward (Juman & James, 2006). Juman (2011) found that seagrasses closest to Buccoo Bay had the highest biomass and areal productivity of all seagrass beds in Tobago.

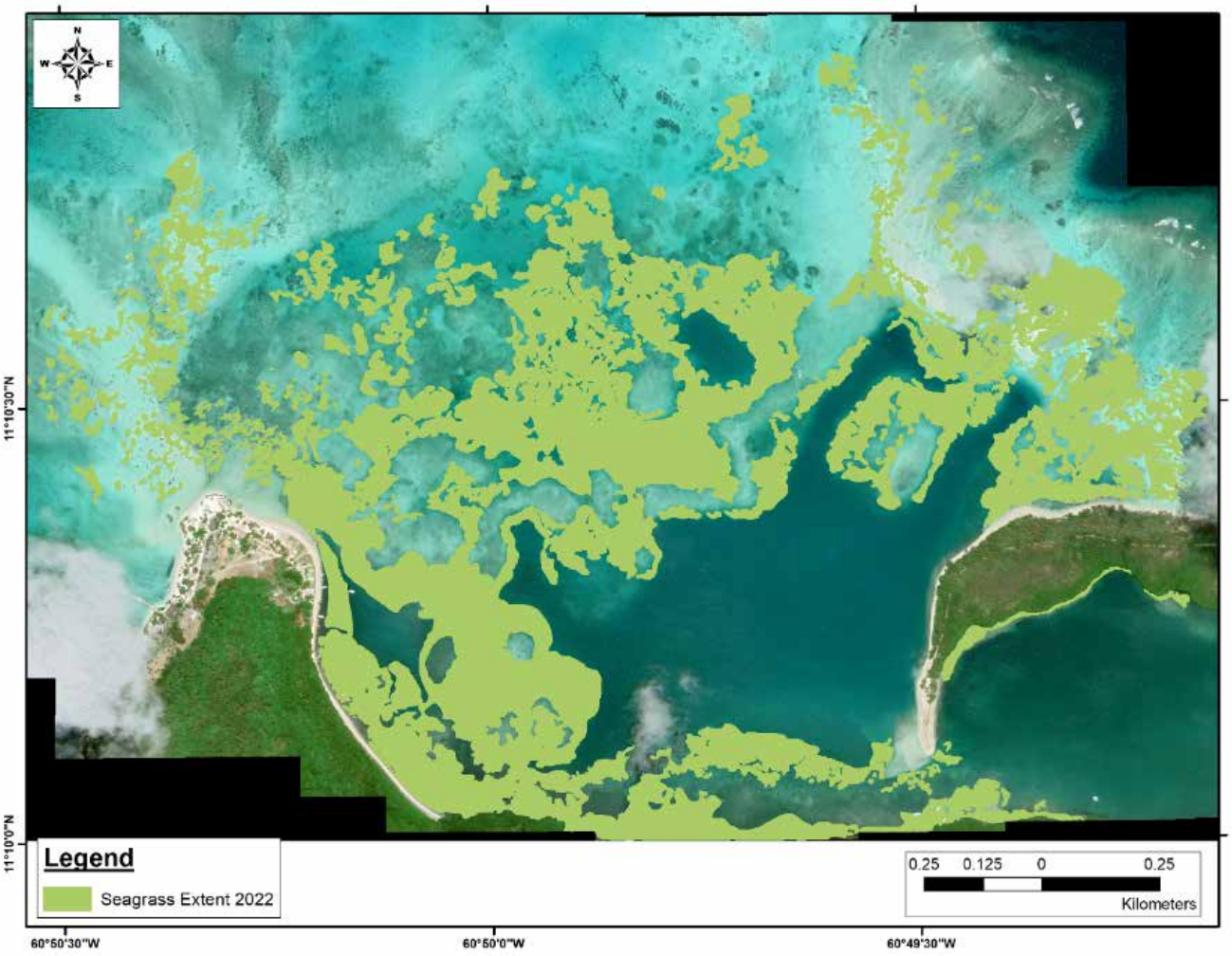


Figure 5 Spatial distribution of seagrass beds in Bon Accord Lagoon in 2022

Despite the expansive area occupied by seagrasses, long term monitoring of seagrass habitats within the Bon Accord Lagoon conducted by the Institute of Marine Affairs has shown a decline in seagrass productivity and biomass from 2002 to 2020 (Plate 2; Figure 6). This decline has been attributed to anthropogenic impacts in the form of nutrient enrichment from sewage effluent in the surrounding area (Juman 2004; Ramoutar and Persad 2018). The proliferation of macro-algae, an ecological indicator of nutrient pollution, can be observed around Bon Accord Lagoon due to these nutrient enriched conditions (Juman 2004). Generally, nutrient loading enhances the proliferation of faster growing phytoplankton, epiphytic and macro-algae that compete with seagrasses for light and space. This competition with algae affects seagrasses by causing slower growth and diminished stature; increased shoot mortality and decline in shoot density and habitat area of seagrasses (Taylor et al., 1995; Kenworthy and Fonseca, 1996; Short and Burdick, 1996). Corresponding with the nutrient enrichment is the proliferation of fast-growing, pioneer species of shoal grass (*H. wrightii*) (Juman 2004). As a result, there has been a gradual shift in the distribution of seagrasses outwards from the Bon Accord Lagoon area, towards the back reef habitats of Buccoo Reef, including the Nylon Pool (Juman 2011; Pers. Obs. 2022).

Plate 2 Seagrass beds of Bon Accord Lagoon. Photo credit Anjani Ganase

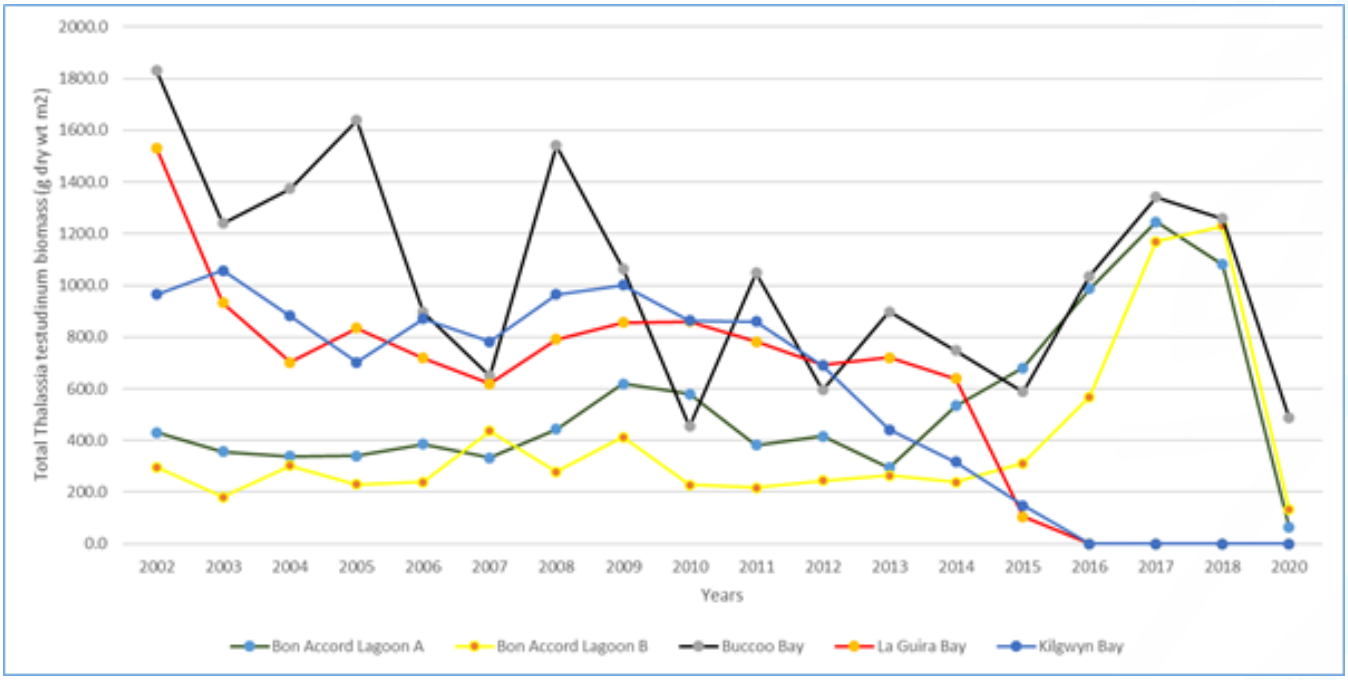


Figure 6 Total *Thalassia testudinum* biomass (g dry wt. m^2) at five long-term monitoring sites in south-west Tobago

South Coast

Other locations where extensive seagrass beds were found were Kilgwyn and La Guira Bay along the south coast of Tobago (Figure 7). However, a number of activities from land reclamation for extension of the airport runway, and coastal erosion caused by sand mining in the late 1980s and early 1990s at La Guira resulted in significant loss of seagrasses (IMA, 1996). Signs of recovery were shown in the early 2000s (Juman et al. 2006; Juman, 2011) (Figure 7).

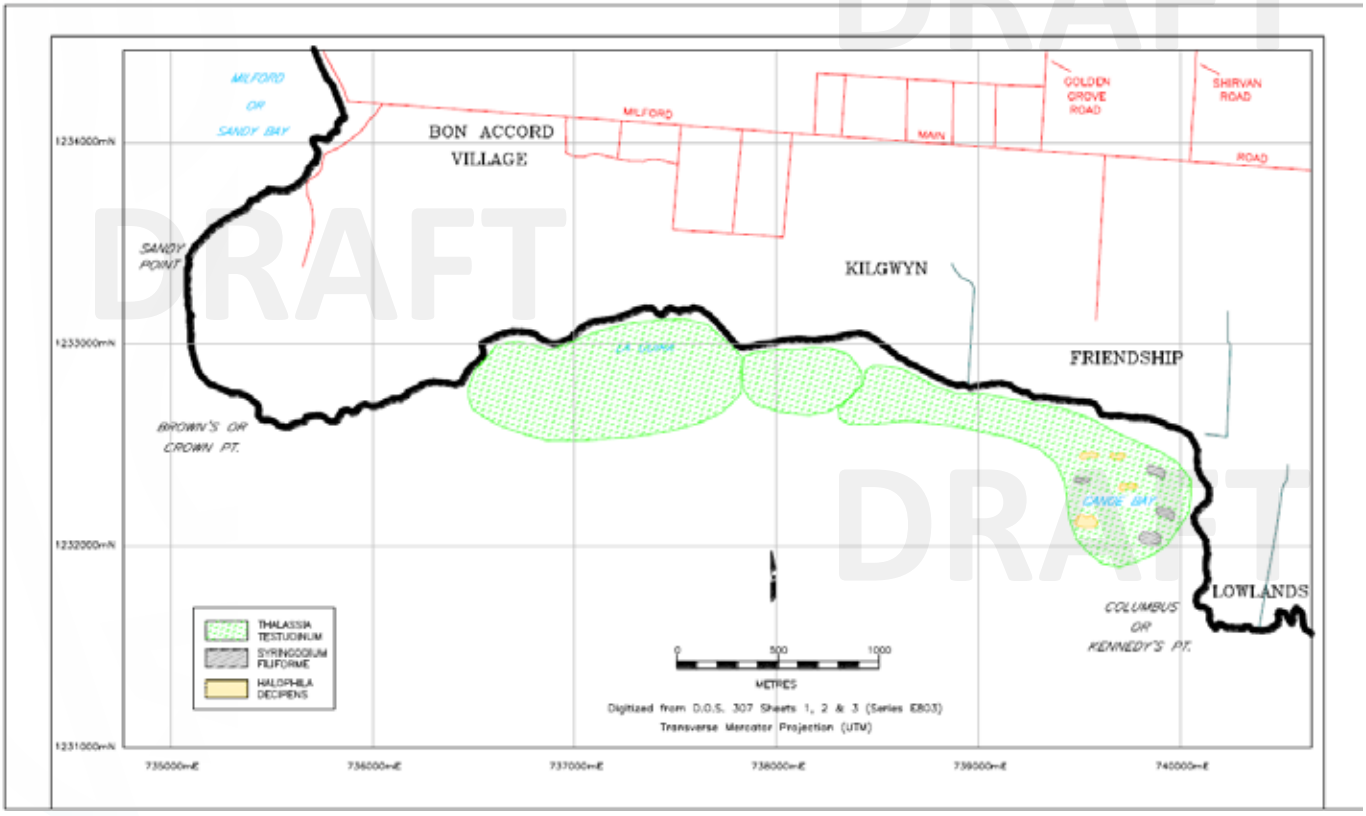


Figure 7 Seagrass distribution from La Guira to Canoe Bay, 2001. Taken from Juman & Alexander, 2006

The adjacent coastal area - Kilgwyn mangrove forest – serves as a catchment for an area comprising guest houses, the airport, residential development and an industrial estate (Juman, 2011). The poor management of the wetland has resulted in sporadic and intentional discharge of large amounts of freshwater, pollutants and sediment during periods of flooding over the adjacent seagrass beds.

Sargassum influxes have significantly increased in the Atlantic region within the last decade. This has negatively impacted coastlines of many Caribbean islands including the Atlantic coastlines of Tobago. Floating sargassum beds settling along the shores of Kilgwyn and La Guira Bay areas have been observed to shade large areas of the shoreline including seagrass areas for extended periods of time (IMA, 2018). The decaying sargassum alters the water conditions - temperature and chemistry - that can degrade the seagrass habitats (van Tussenbroek et al. 2017).

Despite the series of disturbances, seagrasses have been observed to recover following such events. In 2021, various sites along Kilgwyn Bay showed signs of natural recovery (IMA 2020, unpublished) (Plate 3), albeit slowly as patches were sparse in density.

Plate 3 Seagrass recovery in April 2021 resurvey of Kilgwyn Bay. Photo courtesy Anjani Ganase

Climate change and seagrasses

Climate change brings with it several impacts to the seagrass habitats including rising ocean temperatures, extreme storm events, sea-level rise and saltwater intrusion inland, increased tidal height and tidal range and increased carbon dioxide concentrations. Global temperature rise can alter growth rates, reproductive patterns and alter the distribution of seagrasses (Garth Harrison 1982; Durako and Moffler 1987; Short and Neckles 1999; Sunny, 2017).

Changes in salinity can shift seagrass distribution and lead to changes in germination, propagule formation, photosynthesis, growth and biomass (Short and Neckles 1999). Increased salinity can also lead to increased incidents of diseases which can result in the reduction or elimination of entire seagrass communities (Short and Neckles 1999). Increased water depth attenuates the light available to seagrass beds and will directly reduce plant productivity leading to reduced distribution and abundance (Short & Neckles, 1999; Sunny, 2017).

Changes to water motion, including current velocity, circulation flow, and flow duration, all have effects on seagrass plants and habitat structure (Fonseca et al. 1983), all of which are likely to increase as sea-level rise reduces the sheltering capabilities of the adjacent reefs. Tidal height and tidal range, current velocities, depth, and salinity are all factors that regulate the distribution and abundance of seagrasses. Increased tidal range will restrict the depth to which plants can grow due to light limitations (Dring and Lüning 1994).

Rising levels of atmospheric carbon dioxide (CO_2) are predicted to have significant direct effects on global vegetation (Cure and Acock 1986). The potential effects of increasing CO_2 and the impacts of greater UV-B radiation may alter seagrass and seaweed photosynthesis and productivity (Sunny, 2017). However, in areas where seagrasses are carbon limited, this may increase primary production. Whether this increase will be sustained with long-term CO_2 enrichment is uncertain (Short & Neckles, 1999). The combined effects of chronic stressors, such as eutrophication, acute climate disturbances, e.g. extreme weather events can lead to die-off and /or the redistribution of existing seagrass habitats. However, seagrasses can play a key role in climate change mitigation acting as significant carbon sinks with the ability to store blue carbon for extended periods of time (Serrano et al. 2021).

Kilgwyn Bay, another location where seagrass beds are monitored by the IMA. Photo courtesy Anjani Ganase

The Resilience-Based Management Concept

What is resilience?

The modern concept of resilience-based management recognises that human (social) systems are interlinked with natural marine ecosystems (Anthony et al. 2015; Mcleod et al. 2019). For ecological resilience to occur, there must be social resilience, and governance. As a result, strategies in resilience align with socio-economic mechanisms to promote healthy marine ecosystems that continue to provide crucial services and socio-economic benefits. Strategies for building social and ecological resilience are grounded in three foci - *Resistance, Recovery,* and *Adaptation*. For example, ecological resistance benefits from redundancy in ecological functions by conserving the abundance and diversity of key species, while social resistance is supported by socio-economic redundancy in livelihood opportunities by developing diversity in tourism products (Figure 8). For the long-term and for an uncertain future, social and ecological management must also be adaptable, and supported by governance, which is inclusive, collaborative and transparent (Anthony et al. 2015).

> *"Resilience is defined as the ability of a system to maintain key functions and processes in the face of stresses or pressures by **resisting** and then **recovering** or **adapting** to change*
>
> (Holling 1973; Nyström and Folke 2001)."
> *- Reef Resilience Network*

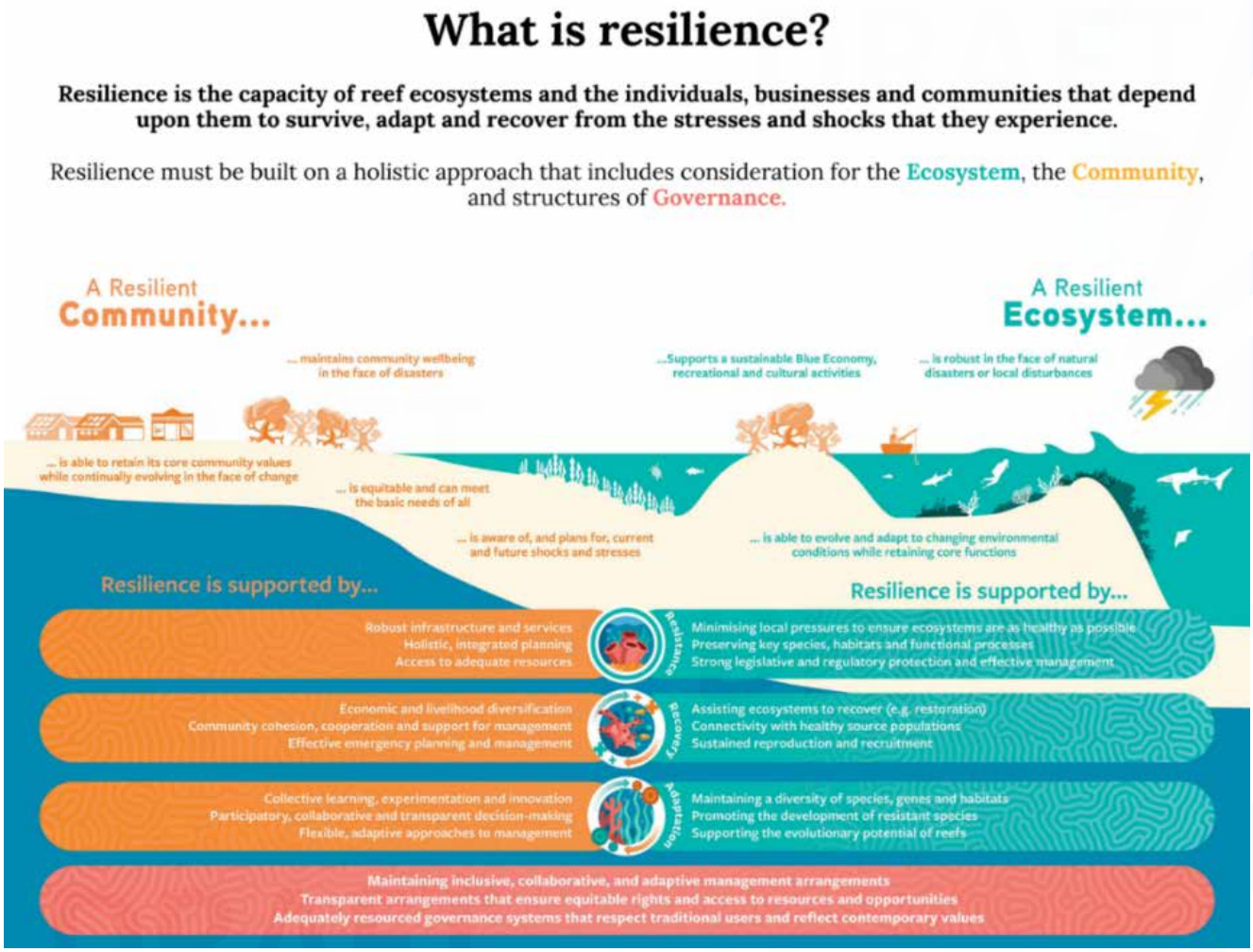


Figure 8 Resilience strategy sourced from https://www.coastalzonebelize.org/portfolio/resilientreefsinitiative/

The decision-making around Resilience-Based Management (RBM) requires a thorough understanding of Tobago's marine environments including its disturbance history, ecological composition, the projected risks, and how these ecosystems are utilised. Such knowledge will prioritise management action to support marine resilience, especially under circumstances of limited resources. Examples of management action may include mitigating habitat loss, such as managing pollution, fisheries, zonation, as well as adapting livelihoods to align with reef health, and supporting ecological processes of recovery by conducting restoration and creating buffer zones for adaptation (Mcleod et al. 2019). RBM also focuses on the rehabilitation of mechanisms that can support the natural processes in resisting disturbances or recovering from one. Additionally, RBM is the adaptation and expansion of traditional management tools to include innovative interventions, such as tools for restoration (Pfefferbaum et al. 2013; Mcleod et al. 2019) and for cost-effective decision-making. This is critically important in an uncertain future where there are several projected climate-related disturbances - extreme storms, coastal erosion, coral bleaching, disease outbreaks and ocean acidification to consider in addition to the chronic pressures of human activities.

Priority management recommendations for Resilience Based Management (Mcleod et al. 2019):

1. Protect a diversity of species, habitats, and functional groups
2. Maintain pathways of connectivity
3. Strategies in stress reduction (especially following a disturbance) (West and Salm 2003; McClanahan et al. 2011)
4. Implement MPAs to support marine resilience
5. Manage adaptively to accommodate uncertainty and change
6. Prioritise areas with low environmental risk and high social adaptive capacity
7. Incorporate social (Hicks et al. 2016) and ecological indicators (Mumby et al. 2014; Maynard et al. 2017; Ford et al. 2018) to assess early warnings, recovery patterns, and regime shifts in conservation planning and monitoring
8. Invest in experimental approaches to support resilience
9. Implement strategies to build social and ecological adaptive capacity (Berkes and Turner 2006; Cinner et al. 2012)
10. Implement strategies to facilitate adaptation and transformation

An adaptive management pathway for Tobago

The marine management pathway should be an adaptive process grounded in resilience principles for each step (Figure 9). The first step - **baseline management –** is focussed on building the resistance of marine ecosystems (coral reef, seagrass, mangrove habitats) by managing current and chronic issues that impair ecosystem health, such as sustainable resource use and maintaining healthy environmental conditions.

The second step in the pathway - **disturbance response planning** - considers any acute disturbance or novel change that has deviated environmental conditions from the norm with ecological/ social consequences to the marine habitats. There are a couple response plans that exist for Trinidad

and Tobago, such as the coral bleaching, and draft sargassum response plans. However, the type of disturbance or the circumstances of disturbance may need novel solutions and interventions to facilitate recovery. This requires flexible and collaborative thinking. Critical to all disturbance response management are facilities for detecting or predicting the disturbance, assessing the extent of damage, communicating the impacts, and management steps for recovery.

The third step – **recovery implementation** - includes actions to reduce the threat, mitigate loss, and to facilitate recovery (including restoration). In circumstances where – **restoration** - is needed, guidelines to determine the type of restoration is required, and is the purpose of this guide.

For all management pathways, inclusive of restoration - **monitoring and evaluation** – is the last required step to determine the need for transformation or adaptation of baseline management. While this document is focussed on developing the decision-making steps to guide restoration of local marine ecosystems, it will be addressed holistically within this concept of resilience-based management.

Figure 9 Schematic of an adaptive management pathway for Tobago

Coral Restoration

Coral Reef Restoration Planning & Design

Restoration works within a continuum of marine management initiatives (Figure 10). While there is a major emphasis on active restoration to mitigate the loss of coral populations, there must be a multidisciplinary approach that is facilitated within the management pathway; one that focuses not only on maximising coral cover and regrowth but also tackles other environmental issues that impair the natural resilience of corals. Issues, such as poor water quality and pollution can reduce the thermal tolerance of corals and increase the occurrence of infectious disease, or poor fisheries management that erode reef food webs (Dulvy et al. 2004; D'Angelo and Wiedenmann 2014). When deciding to conduct coral restoration, the first step is to determine whether restoration (and the type of restoration) would significantly improve the survivorship of corals on the reef. Furthermore, there are several factors to consider including the pre-existing ecological community, its history of disturbance, current state of health, its environment condition and connectivity, any anthropogenic influence, as well as the future vulnerability to disturbance, the socio-economic value of the reef, and the availability of resources. Many of these factors will be discussed in this guide.

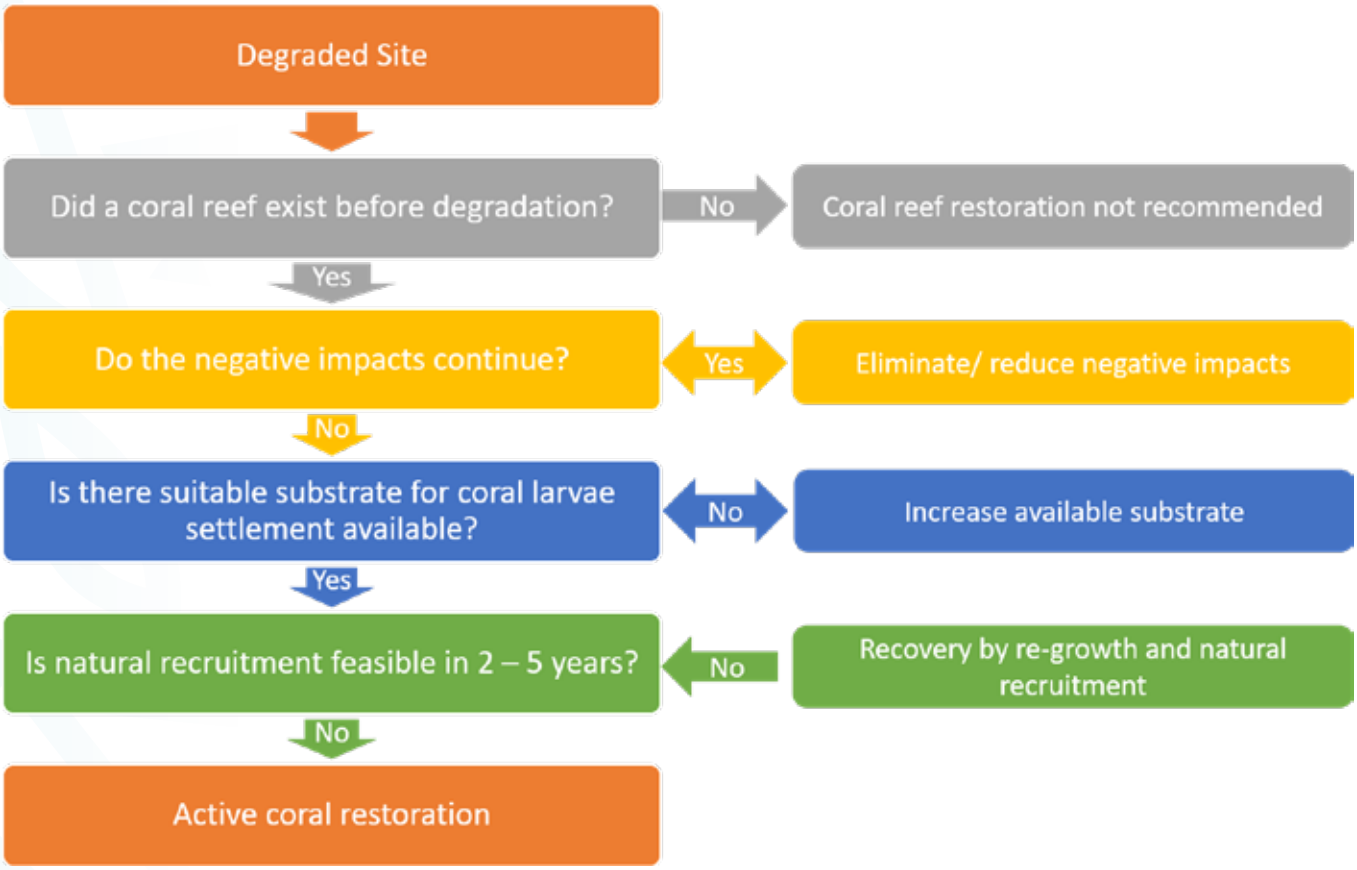


Figure 10 Flow chart indicating potential for active restoration at a coral reef site (Frias-Torres et al., 2018). Copyright © 2018, Nature Seychelles.

Once restoration is feasible, there are four planning steps for conducting coral restoration derived from Shaver et al. 2020 - *A Manager's Guide to Coral Reef Restoration, Planning and Design* (Reef Resilience Network). Proper engagement with stakeholders, experts and managers must be done at all decision-making steps for inclusive decision-making and information gathering. This is critical in order to maximise restoration success. Below is an outline of the steps for planning and designing for coral restoration (Shaver et al., 2020):

1. **Set goal and geographic focus**
    a. Undertake stakeholder engagement for planning and implementation, and to identify needs/ contributions/ roles.
    b. General considerations for the area of interest:
        i. The current state of health of the site
        ii. Existing threat, environmental conditions, and the current management of these threats
        iii. Site connectivity - upstream influences, downstream impacts, and the management of these associated areas
        iv. Socio-economic use of the area
    c. Identify the characteristics of the 'target' ecosystem state, and the objectives of the restoration
2. **Identify, prioritise and select sites**
    a. Conduct a resilience assessment using ecological indicators, such as coral diversity, proportion of heat stress tolerant coral species, coral recruitment, and herbivory diversity and abundance (Maynard et al. 2017).
    b. Conduct a vulnerability assessment for the area of interest, based on the current resilience scores, identifying the main exposures (chronic stressors) and sensitivities of the reef (e.g. history of bleaching) and the adaptive capacity (mechanisms to improve) (Maynard et al. 2017).
    c. Identify any other consideration for site selection, such as MPA status, cultural value.
    d. Select sites based on the best combination of low vulnerability to climate change and human impacts, and high potential for ecological resilience.
3. **Identify, design and select interventions**
    a. Considerations include the effectiveness, sustainability, expertise, cost and logistics
    b. Consider accompanying management interventions for the site
    c. Consider cross-sector collaborations, and regional and international partnerships.
4. **Develop a restoration action plan**
    a. Write SMART (specific, measurable, achievable, realistic and time-bound) objectives for each restoration objective
    b. Include resource budget, timelines and personnel

c. Include community engagement and management support

d. Consider climate adaptation into the design (such as buffer zones or marine spatial planning).

Following these planning steps, restoration implementation, and monitoring and evaluation of coral survivorship can proceed. Here are some considerations for the next two steps:

5. **Implement Restoration Plan**

    a. Must include a restoration blueprint for goals, objectives, site selection, restoration strategies, funding and personnel resources and timelines

    b. The plan must be inclusive of stakeholders and community members, and align with other activities in the area.

6. **Monitor and evaluate progress**

    a. Consider the Before - After - Control - Impact method for measuring progress

    b. Consider the use of community members and partners for monitoring.

Strategies in coral restoration

Ecological restoration refers to the process of assisting the recovery of a habitat that has been degraded or destroyed (Balensiefer et al. 2004). Restoration can be either passive or active. Passive techniques rely on the natural increase in population without direct intervention after the removal of the causal factors resulting in coral mortality or the rehabilitation of the surrounding conditions that would promote natural recovery. Active restoration focuses on reintroduction of corals (coral fragments or recruits) or augmentation of coral reproductive process (use of recruiting tiles, nursery sites, ex-situ tanks, substrate improvements etc.) to directly increase coral populations, and speed up coral regrowth. Restoration and implementation of propagation technologies have shown to be beneficial to speed up reef recovery (Rinkevich 2014). Over the past ten years, coral restoration research has advanced considerably and has become more applicable to coral reefs at larger scales.

Types of Active Restoration Techniques

Regarding active restoration, there are several methods that can be applied depending on the goal of the restoration. The selection of a methodology is governed by ecological and logistical considerations, including restoration goal, the target site, species, recovery success metrics, personnel and funding availability.

Physical restoration refers to the restoring of the physical structure that was lost, typically from storms or human activities, such as dredging. Coral rubble formed in the aftermath are often not suitable for coral recruitment until it is stabilised by natural substrate binders -sponge, calcareous algae (Ceccarelli et al. 2020). At sites, where there is a lot of wave action, for example, this first phase may take longer, and the use of artificial stabilisation strategies may speed up substrate stabilisation either by binding rubble artificially or the installation of a replacement secured artificial framework to encourage natural recruitment of corals. Substrate stabilisation using mesh or plastic netting encourages the natural binding and cementing of the reef substrate by marine sponges, coralline

algae and other natural colonisers. Artificial structures are secured to the reef substrate, their shape provides cryptic spaces to encourage recruitment and improve recruit survival, or direct attachment of corals. Physical structures may also serve as a fish and invertebrate refuge, especially grazers that feed on algae to encourage reef acquiescence. Physical restoration is often implemented in conjunction with biological restoration such as direct transplantation of corals (Ceccarelli et al. 2020).

Biological restoration strategies work to enhance the coral's asexual or sexual reproductive strategies.

Asexual reproduction is the genetic cloning of cells to create new colonies and increase growth. The main practised propagation strategies by asexual means include direct transplantation, coral gardening, and micro-fragmentation. While genetic diversity of the existing adult population is maintained through colony selection and tracked throughout the restoration processes to assess and select against vulnerability, genetic recombination does not occur.

(1) *Direct transplantation* refers to the direct transplantation of coral colonies or fragments from a donor reef to a recipient reef without the use of a nursery (Boström-Einarsson et al. 2020). This is one of the earliest methods of coral restoration and is often used in situations where coral remnants are salvaged from a disturbed or damaged site. According to Boström-Einarsson et al. (2020), a review of 94 studies on direct transplantation methods revealed an average survival rate of 64 % (20 % of the studies showed > 90 % survivability) (Boström-Einarsson et al. 2020). However, much of the monitoring for survival only occurs for one year after the restoration activities, and long-term monitoring is needed to corroborate success. For this method, branching corals were most frequently used (59 % of the studies), and less is known for massive growth forms.

(2) *Coral gardening* - Coral fragments are sourced from a donor colony and grown in an intermediary setting, such as a coral nursery, which can be in situ or ex situ in tanks. In situ nursery structures are commonly in the form of table nurseries, rope nurseries or nursery trees (Plate 4). This intermediate stage facilitates growth of the fragments in a more protected environment before the corals are outplanted. Once coral fragments have achieved a large enough size threshold for their increased survivability, they are attached to the reef needing restoring. Again, branching growth forms are predominantly used in this method. According to Boström-Einarsson et al. (2020), coral gardening has a 66 % survivability. However, this value is likely an underestimation of the restoration success, as coral outplants from nurseries are typically larger in size owing to the faster growth rates in the nursery (Griffin et al. 2012; Lirman et al. 2014; et al., Henry et al. 2021)

Coral trees and table nurseries are both considered fixed structures as they are both anchored into the seafloor. These have higher durability to withstand strong currents due to closeness to the seafloor. However, metal table nurseries anchored into the substrate are particularly considered long lasting and resistant to storms and hurricanes (Bowden-Kerby 2014; Maurer et al. 2022). Table nurseries can also withstand a higher weight threshold for coral growth compared to rope and tree nurseries (Bowden-Kerby 2014). Installation of nurseries at a depth lower than the surrounding reef can increase their protection during strong wave action (Bowden-Kerby 2014). Coral trees may be more susceptible to dislodgement during storm activity however, advantages include adjustability of the height of the tree as well as easy portability in case of an emergency (Nedimyer et al. 2011).

Use of coral nurseries also supports the goal of building genetic diversity to enhance coral reef resilience. Trees and tables are commonly populated with different coral *genotypes* that can be tracked by phenotypic (physical) traits to determine potential superiority for further use in management strategies (Lirman et al. 2014). For example, corals with a faster growth rate in nurseries can reach sexual maturity faster. However, there are trade-offs according to Lirman et al. (2014), while larger sizes have a greater maturity and spawning potential (sexual reproduction), there is a decrease in productivity (growth and structural formation). Therefore, depending on the goal of the restoration, decisions between coral productivity and maturity must be made.

Plate 4 Coral trees in Florida (top).
Photo courtesy Ocean Image Bank, Christophe Bailhache

Table nursery in Belize. Photo courtesy Fragments of Hope Belize, 2022.

Micro-fragmentation - A section of a coral colony is cut into small pieces approximately 1-2 cm² and attached to a substrate, for example cement "cookies," in a process that stimulates faster growth in coral fragments. The fragments of the colony grow and fuse to reform a colony over 12 months. Corals grown from micro-fragments also reach sexual maturity faster compared to corals that grow in the wild, which can take up to 10 years (Page and Vaughan 2014).

According to Boström-Einarsson et al. (2020), less than 5 % of existing studies focus on slow-growing, massive and bouldering morphologies, despite massive and slow growing forms being the dominant group on Caribbean coral reefs. A short-term, ex-situ trial experiment conducted by Mote Marine Laboratory Research reported high survival and rapid growth of micro-fragments with more than 99 % survival in tanks (Page and Vaughan 2014). In-situ experiments investigating, comparisons of survivability between larger verses smaller (aka micro) fragments showed no difference in survival for *Orbicella faveolata* and *Montastraea cavernosa* outplanted on reef sites, however micro-fragments grew at a significantly faster rate (Page et al. 2018). Micro-fragments may have high vulnerability in the early stages hence monitoring the different genotypes against an array of environmental parameters and conditions is important to maintain high survivability (Rivas et al. 2021).

<u>Additional considerations for asexual propagation</u>

There are few long-term studies that assess restoration success beyond 12 months of monitoring and survival rates should be viewed with caution when selecting methods. However, while 12 months is a short time, corals are most vulnerable in their early and smaller stages with lower mortality rates as they age and grow. Strategies should also be piloted on a small scale. Donor colonies must have at least 75 % living tissue and no more than 10 % of the colony should be removed for transplanting to avoid damaging the source material. This places an importance on protecting wild stock populations

which are increasingly affected by disease and predation and new mortality resulting in tissue loss. While not explicitly stated in literature, donor colony stocks should be tracked to reduce the possibility of colonies being used multiple times in quick succession as it may negatively affect the donor coral health.

Sexual reproduction refers to the fusion of male and female gametes to form new offspring which are genetically different, and larval propagation strategies work to enhance the success of sexual reproduction, settlement and survival in the early stages of coral recruitment.

(1) *Larval propagation*, also known as larval enhancement or larval re-seeding, focuses on improving larval production, settlement rates and survival in the early stages of recruitment. This strategy is non-invasive, yet effective, especially against a future of unknown disturbances. The method increases the genetic diversity due to cross fertilisation of gametes released by parent colonies. About 1.3 % of existing studies focus on larval propagation with direct seeding onto the reef or settlement onto artificial substrate units. In a study conducted by Chamberland et al. (2017), there was a survival rate of 10 % of settled *Favia fragum* larvae with 56 % of substrate units having at least one settled *F. fragum* larvae after a year (Boström-Einarsson et al. 2020).

While rates are seemingly low, this method is still highly useful as it speeds up the outplanting process compared to the more laborious process of individual handling of fragments. Strategies for improving propagation success include increasing the number of successful recruits and their survival per tile through tile design and preconditioning with crustose coralline algae. According to Miller et al. (2022), eight out of ten trials for larval propagation using Coral Rearing In-situ Basins (CRIB) successfully yielded 1 % to 11 % settlement of the fertilised larvae (SECORE International). For a CRIB housing up to 700 substrates, ~77 - 100 % of the substrates had at least one coral settler on it for outplanting (Miller et al. 2022; Plate 5). Notably, settlement efficiency in the CRIBs was similar to land-based nurseries (Miller et al. 2022). A pictorial outline of the larval-propagating processing can be found in Plate 6.

Challenges to larval propagation strategy is associated with the decline in healthy sexually reproductive colonies, and less predictable and asynchronous spawning because of warming events. Additional challenges include the survival of the outplanted corals, especially in environments with existing issues of high macroalgae cover. Suitable site selection is important.

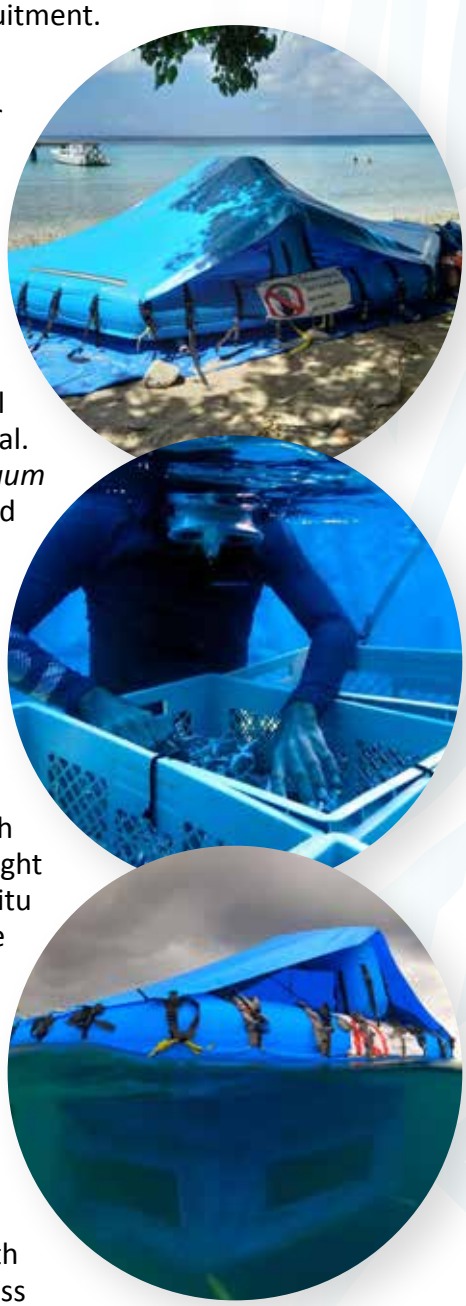


Plate 5
Coral Rearing In-situ Basins (CRIB) developed by SECORE International for coral larvae rearing and settling.
Photo credits:
Hannah Lochan, Anjani Ganase

Plate 6 From left to right: Process of coral gamete collection from a spawning coral, cross fertilisation and rearing of larvae, and eventual settlement of larvae on a seeding unit (inset photo for reference of coral settler on seeding units) (Photo credits: Carolina Marcías, SECORE International, Hannah Lochan)

Overview of pilot study activities to assess restoration feasibility

The MARIN pilot project worked to fill some gaps in knowledge that included preliminary investigations for the purpose of site selection for prioritised restoration. A pilot set of reef sites that span the geographic area of Tobago were the focus of the initial activities. The three main objectives were:

- To assess the current ecological state of five pilot coral reefs in Tobago to determine resilience and vulnerability for management/ restoration prioritisation
- To record patterns of coral spawning and recruitment on Tobago's coral reefs to guide the intended coral larvae propagation restoration strategies
- To introduce stakeholders to the concept of coral reef restoration and garner interest for conducting specific activities, such as coral spawning observations, that is aligned with eco-tourism.

OBJECTIVE #1: To assess the current ecological state of five pilot coral reef sites in Tobago to determine resilience and vulnerability for management/ restoration prioritisation

Scoring for Reef Resilience

Ecological surveys to assess relative reef resilience were conducted at five pilot sites in June 2022. Three sites in the south west: Flying Reef, Buccoo Western, Mt Irvine Reef, and two sites in the north east - Booby Island Reef, and Angel Reef (Figure 11).

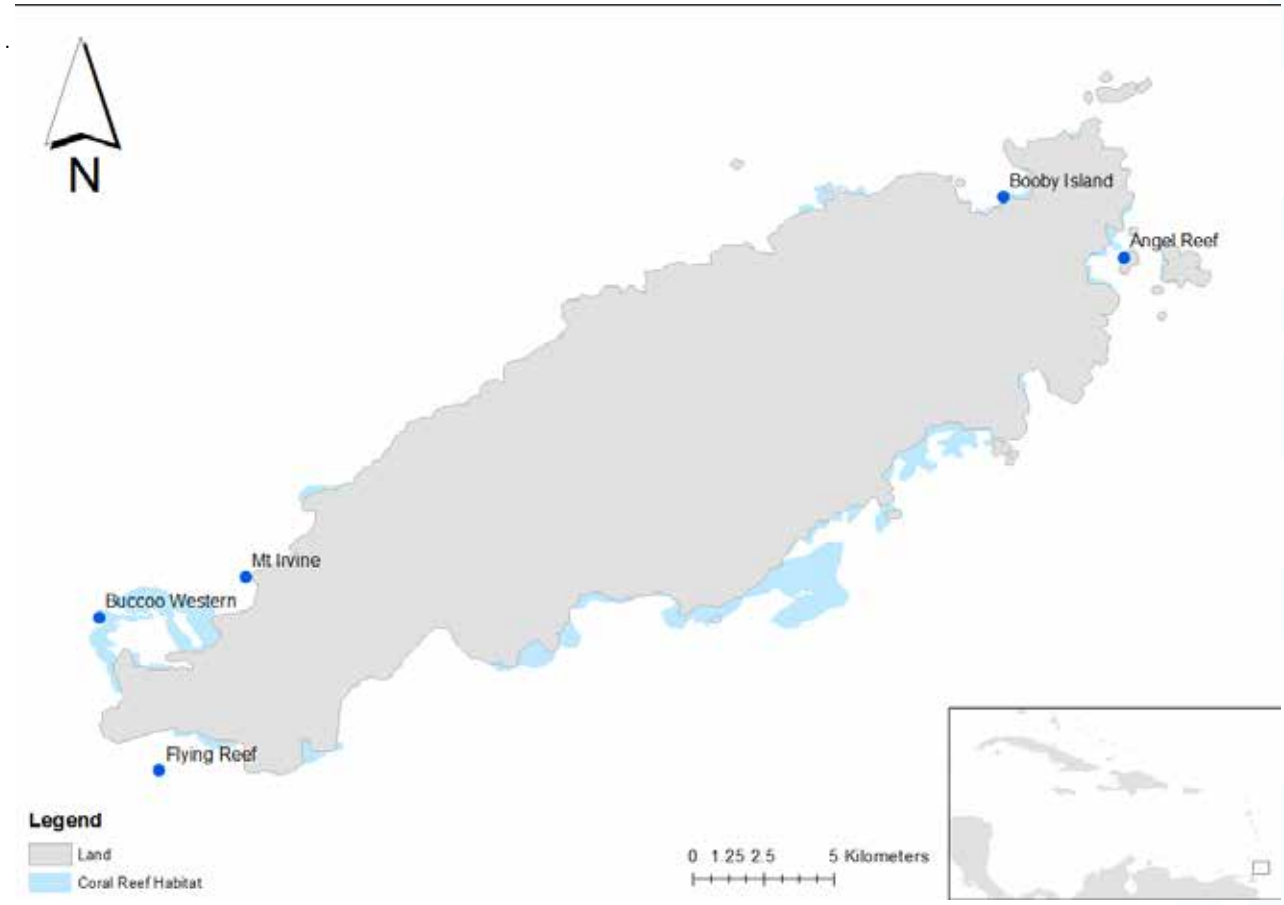


Figure 11 Coral reef pilot sites. Three reefs in the south west – Buccoo Western (present in the marine protected area), Flying Reef and Mt Irvine Reef, and two reefs in the north east – Booby Island in Charlotteville and Angel Reef in Speyside

The relative reef resilience of each site was assessed using the methodology of Maynard et al. (2017) - *A Guide to Assessing Coral Reef Resilience for Decision Support*. Ecological indicators of resilience refer to specific metrics that determine the likelihood that a reef may resist or recover from a disturbance, such as coral bleaching (Maynard et al. 2017). For this study, a minimum of six indicators of resilience were assessed:

1. **Hard coral diversity** – A measure of the number of different hard coral species present and their relative quantities. Higher resilience is associated with greater hard coral diversity providing more functional diversity for habitat provision and redundancy. Higher hard coral diversity is associated with greater reef resilience.

2. **Hard coral cover** - Greater hard coral cover, especially of stress-tolerant species[1], is associated with reefs with a higher resistance to stress events. Hard corals are the main functional group responsible for reef building and habitat provision. Higher hard coral cover is associated with greater reef resilience.

3. **Coral recruitment density** - The density of coral colonies that are < 5 cm in diameter as an indicator of coral population replenishment. Higher densities of coral recruits are associated with greater reef resilience and a higher potential for recovery following a disturbance.

4. **Coral disease** - An indicator of the trajectory of coral survival for the area. Corals impacted by disease may eventually die but also infect neighbouring coral colonies. Higher disease prevalence is associated with lower reef resilience.

5. **Herbivore biomass** - Herbivorous fish species primarily graze on algae, a major competitor of hard corals for space. Herbivores clean the surfaces of algae to aid coral recruitment and prevent algae overgrowth. Higher herbivore biomass is associated with higher reef resilience facilitating quicker recovery for hard coral communities following a disturbance through grazing of algae from reef surfaces.

6. **Algae cover** - Algae (long filamentous turf algae and fleshy macroalgae) pre-empt coral recruitment and growth by pre-occupying reef surfaces, as well as by trapping fine sediment. Higher algae cover is associated with lower reef resilience because of space pre-emption and greater likelihood of smothering coral recruits. Higher algae cover may also be associated with reefs that are overexploited of herbivores and / or nutrient pollution promoting algal blooms.

Additional ecological indicators (reef structural complexity, herbivore diversity, coral size classes) and anthropogenic stressors (sedimentation, nutrients, physical human impact, and fishing pressure) may be included for more comprehensive assessments of reef resilience (Maynard et al 2017). Over time, knowledge of the reef impacts may place greater weight on some indicators. For now, we used previous literature to inform the other factors.

The relative resilience index ranked sites based on their relative scores for each indicator. Each indicator value was normalised to range between 0 – 1 and made unidirectional so that all values closer to 1 represent greater resilience potential. All scores were added together to determine a cumulative resilience score for each site, which was then classed into four categories – *High, Medium to High, Medium to Low*, and *Low*. These categories assisted in prioritising site selection for restoration.

1 Heat stress tolerant species are not known for the Caribbean. Therefore, hard coral cover refers to all species present in Tobago

Assessing vulnerability to climate change (coral bleaching)

To assess vulnerability of coral reefs to climate change for the pilot we focussed on the risk of coral bleaching as a function of their resilience and the level of exposure to projected thermal stress scenarios (Maynard et al. 2017). Climate change is expected to increase the frequency and severity of thermal stress events on coral reefs (van Hooidonk et al. 2015, 2016). Here, we used a model developed by Hooidonk et al (2016) projecting the onset of annual severe coral bleaching under the worst-case climate scenario – Representative Concentration Pathway (RCP) 8.5 (4-km resolution based on IPCC Coupled Model Intercomparison Project phase 5 (CMIP5); van Hooidonk et al. 2016). The range of exposures experienced across the sites were ranked and divided into four classes (*High, Medium-High, Medium-Low*, and *Low*). A Vulnerability Matrix was used to relate relative reef resilience and coral bleaching exposure to four classes of coral bleaching threat to determine vulnerability: *High, Medium-High, Medium-Low,* and *Low* (Table 1). The vulnerability scores were considered in site selection for restoration.

Table 1 Climate vulnerability assessed based on four categories of resilience and risk (potential exposure to annual severe bleaching)

Exposure risk to coral bleaching	Resilience				
	High	Medium-High	Medium-Low	Low	
Low	Low	Med-Low	Med-Low	Med-High	
Medium-Low	Med-Low	Med-Low	Med-High	High	
Medium-High	Med- Low	Med-High	High	High	
High	Med-High	High	High	High	

Outcomes of Objective #1

Resilience Scores

The resilience assessment of pilot sites revealed that many reefs suffer relatively low densities of coral recruits, low herbivore biomass, while a few sites have relatively lower coral diversity and higher cover of algae (turf and macroalgae) placing them into the *Low* and *Medium to Low* categories for resilience. The only site with a *High* relative cumulative resilience score was Mt Irvine Reef (0.78), driven by the high scores in coral diversity (0.56) and absence of algae (0.71), followed by *Medium to High* coral cover (0.46) and absence of coral disease (0.91) (Table 2). Two sites were placed in the *Medium to High* relative resilience category – Buccoo Western (0.69) and Booby Island (0.68). Buccoo Western had two indicators in the *Medium to Low* category – coral recruitment (0.13) and herbivore biomass (0.12), while Booby Island scored in the *Medium to Low* category for coral diversity (0.37) and absence of algae (0.42). Angel Reef was placed in the *Medium to Low* resilience category with the lowest score for absence of coral disease (0.47), and *Medium to Low* scores in coral diversity (0.34) and the absence of algae (0.43), despite having the *High* score in coral recruitment (0.31) and herbivore biomass (0.58). Flying Reef had a *Low* cumulative resilience score, with the lowest hard coral cover (0.11) and coral recruitment (0.02), and *Medium to Low* scores for the remaining indicators (Table 2). For more detailed analysis of the resilience study, please see the supplementary document: MARIN Tobago, coral reef scientific report.

Table 2 Relative reef resilience scores for five pilot sites

Site	Coral diversity	Hard coral cover	Coral Recruitment	Absence of coral disease	Herbivore biomass	Absence Algae cover	Cum. Score (norm.)	Score category
Mt Irvine	0.56	0.46	0.15	0.91	0.18	0.71	0.78	High
Buccoo Western	0.46	0.43	0.13	0.95	0.12	0.50	0.69	Medium to High
Booby Island	0.37	0.45	0.22	0.87	0.53	0.42	0.68	Medium to High
Angel Reef	0.34	0.57	0.31	0.47	0.58	0.43	0.63	Medium to Low
Flying Reef	0.38	0.11	0.02	0.75	0.05	0.35	0.45	Low

Vulnerability to climate change (coral bleaching)

The projected onset of annual severe bleaching (ASB) for Tobago under worst case scenario (RCP 8.5) shows that most reefs around Tobago are likely to experience ASB between 2040 – 2050, except for areas around Charlotteville (Booby Island) and Speyside (Angel Reef), which are projected to experience ASB in the following decade (van Hooidonk et al. 2016; Figure 12). Flying Reef has the highest climate vulnerability score based on its relatively higher climate exposure score (ASB onset ~2047) and low cumulative resilience score (Figure 12). Mt Irvine Reef, Buccoo Western, and Booby Island all have similar risk to coral bleaching as Flying Reef, but their *High* (Mt Irvine) and *Medium to High* (Buccoo Western, Booby Island) resilience scores place them at a *Medium to Low* vulnerability (Figure 12). Angel Reef has a *Medium to High* vulnerability owing to its *Medium to Low* resilience score, despite having a delayed exposure to ASB (onset ~2051). No sites had low vulnerability to this climate change risk.

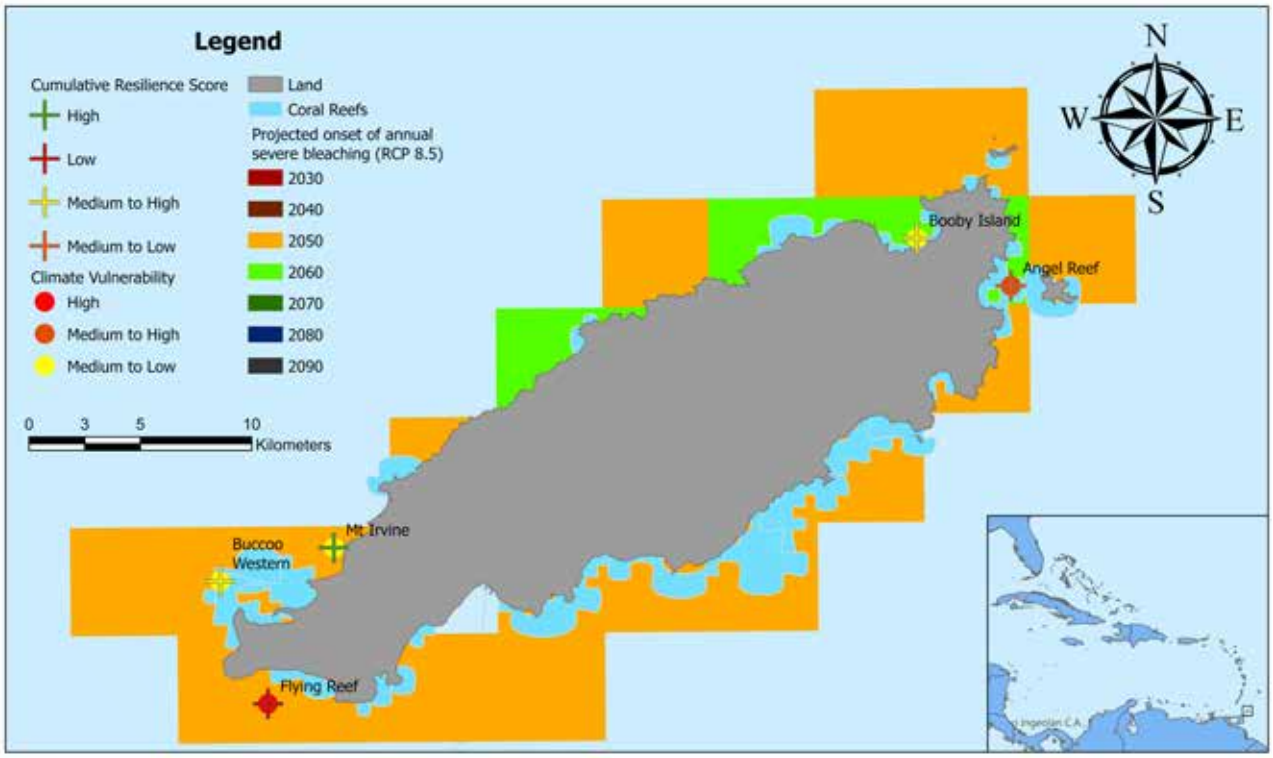


Figure 12 Map showing vulnerability to coral bleaching based on reef resilience scores and projected exposure to annual severe bleaching in the future.

OBJECTIVE #2: To record patterns of coral spawning and recruitment on Tobago's coral reefs to guide the intended coral larvae propagation restoration strategies

Coral spawning was monitored during the 2022 spawning season (May to October), at two sites. Mt Irvine Reef in south-west Tobago was observed in July and August, and Booby Island reef in September and October for most coral species. As spawning of the grooved brain coral (*Diploria labyrinthiformis)* was not observed during the fall (July/ August) of 2022, additional monitoring in the spring (May/ June) months of 2023 at Mt Irvine reef (May) and Booby Island Reef (June) was conducted. Sites were selected based on coral species diversity, and logistical considerations for safe observations. All monitoring occurred over a ten-day window following the full moon.

Species of massive and boulder coral (*Orbicella faveolata, Pseudodiploria strigosa, Colpophyllia natans, Siderastrea siderea, Montastraea cavernosa, Diploria labyrinthiformis, Meandrina meandrites, Dichocoenia stokesii*) at 8 – 12 m depth were monitored for the four months to determine the peak spawning month, and spawning nights after full moon. Ad hoc monitoring of the branching coral, *Acropora palmata,* was done at Mt Irvine Reef (1 - 3 m) during August. Spawning prediction times were derived from the Southern Caribbean calendar (CARMABI Research Station) and with guidance from SECORE International. When coral spawning occurred, spawning times were recorded, and colonies were tagged. Where possible, spawning nets were used to collect sperm/ egg bundles for the hermaphroditic (coral polyps that are both male and female) species and the syringes to collect sperm and egg of gonochore (coral polyps that are either male or female) species for fertilization.

During the spawning season, clay tiles were placed on the five pilot sites from July to January 2022 to estimate coral settlement. Tiles were counted for living coral recruits and dead coral recruits. The substrate composition of the tiles associated with the recruits were also quantified. Please refer to the supplementary document: MARIN Tobago, coral reef scientific report for more details.

Outcomes of Objective #2

Over the four-month window, coral spawning was observed in seven species of hard corals. The three most prevalent spawners were the mountainous star coral (*Orbicella faveolata*), boulder star coral (*Colpophyllia natans*) (Plate 7) and symmetrical brain coral (*Pseudodiploria strigosa*) with spawning peaking in July (Figure 13). Other observed species were the great star coral (*Montastraea cavernosa,* male; 16 colonies in July, 2 colonies in August), Elkhorn coral (*Acropora palmata;* nine colonies in August), blushing star coral (*Stephanocoenia intersepta;* two colonies in October), and the maze coral (*Meandrina meandrites,* male; two colonies in October). Spawning of non-coral species was also observed, including a species of white encrusting zoanthid (*Palythoa caribaeorum*) and sea plumes (*Antillogorgia spp*.).

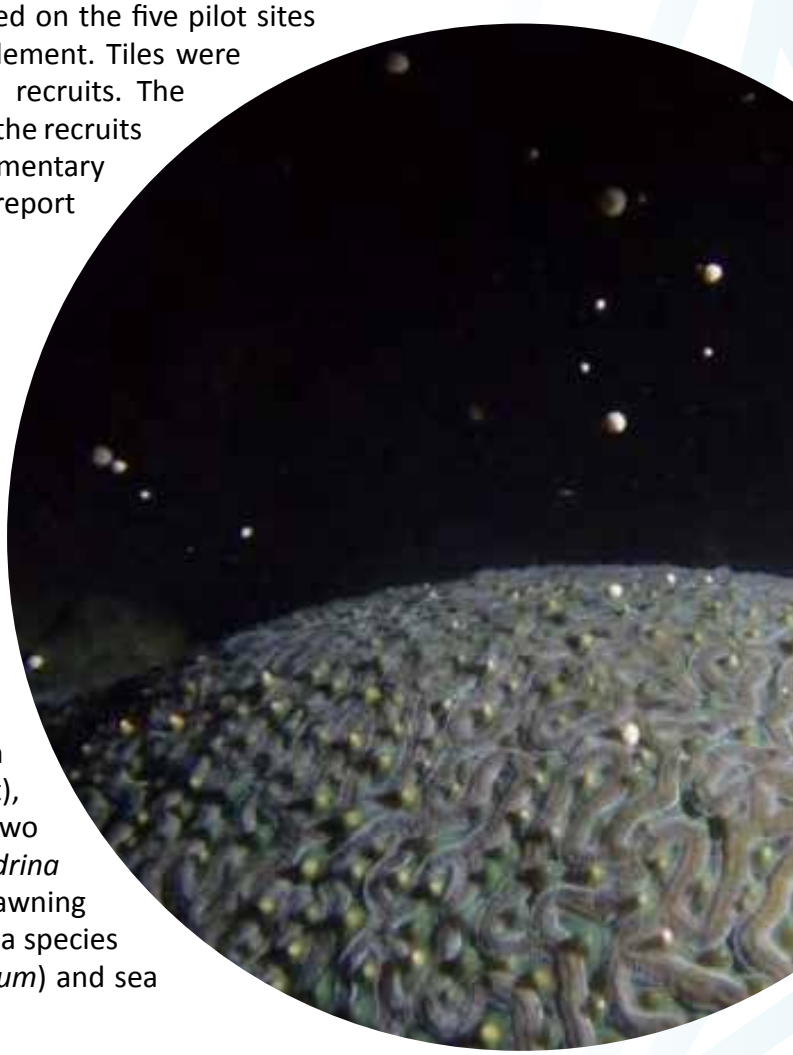


Plate 7 Boulder star coral (Colpophyllia natans) spawning on Mt Irvine Reef in July 2022. Photo courtesy Anjani Ganase

The largest observed spawning event occurred in July 2022, with a decline in the number of colonies and species spawning observed over the following three months (Figure 13). Spawning was observed for the grooved brain coral *(Diploria labyrithiformis)* in 2023, one colony in May 2023, and six colonies in June 2023. Coral spawning was not observed in the following commonly found species: massive starlet coral (*Siderastrea siderea),* elliptical star coral *(Dichocoenia stokesii),* knobby brain coral *(Pseudodiploria clivosa),* great star coral (M*onstrastraea cavernosa,* female), maze coral (*Meandrina meandrites,* female), and smooth flower coral (*Eusmilia fastigiata)*. For detailed results on spawning times and alignment with the Southern Caribbean spawning calendar, please see the supplementary document: MARIN Tobago, coral reef scientific report.

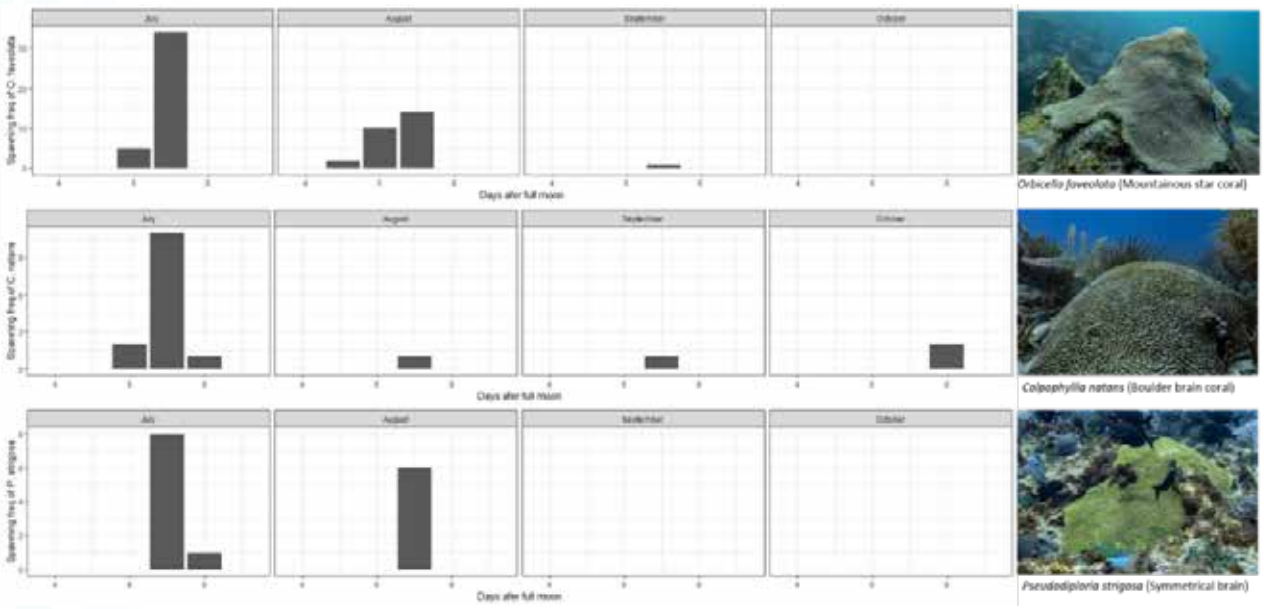


Figure 13 Spawning frequency of the three most observed species of coral during spawning season

Settlement tiles showed low to no coral recruitment across pilot sites. Angel Reef, similar to the coral recruitment survey, had the highest density of settled corals on the tiles, however, many of the species settled were likely to be brooding (species with internal fertilisation and embryogenesis, and the release of larvae into the water column) species e.g., *Agaricia agaricites*. No settlement of recruits was observed at Booby Island, and Mt Irvine had the lowest density of settled recruits (only one observed). This data supports the coral recruitment surveys showing severely impaired recruitment on the reef.

OBJECTIVE #3: To introduce stakeholders to the concept of coral reef restoration and garner interest for conducting specific activities, such as coral spawning observations, that is aligned with eco-tourism

The IMA hosted several stakeholder workshops to introduce the concept of coral restoration in Tobago and associated activities such as coral spawning observations. During the introductory meetings held in January 2022, the team encouraged volunteers from dive tour operators, government partners and NGOs to sign up and join spawning trips. A total of three coral spawning workshops were carried out in 2022, the first was conducted online in June, while the latter two were done “in-person” at the Buccoo Multipurpose Facility in July in south-west Tobago, and the Charlotteville library in September

in north-east Tobago. The locations of the workshop were areas where coral spawning observations were being made (Mt Irvine and Booby Island respectively). An additional informal meet up was held at the Charlotteville pavilion to introduce coral spawning to community members and highlight the spawning events happening on the reefs in Charlotteville.

Outcomes of Objective #3

Overall, workshops were well attended by 76 participants from 24 groups including representatives from government entities, NGOs, businesses, dive clubs, schools and individuals (Plate 8). Outcomes of introductory meetings revealed considerable interest from NGOs and students to determine ways they can assist not only in the activities of restoration, but also in activities to support the restoration success through outreach and education, and community-based management. The importance of having management awareness would play a critical part in successful restoration and should be worked on in tandem. From external discussions and experiences of restoration and management in the Caribbean, there should be opportunities for training about coral restoration during the planning, designing and conducting community workshops. This guide generated for Tobago, along with future workshop sessions would target local groups, including NGOs, associations and environmental groups, to build their capacity to be able to responsibly carry out restoration (and management) with success and benefits. More broadly, it was suggested that the MARIN project can be an opportunity for educating students on Tobago's marine ecosystems either through classroom visits, or fieldwork opportunities for secondary school students (CSEC and CAPE year groups), and undergraduate experiences for tertiary students.

Plate 8 Workshops on coral spawning Buccoo, south-west Tobago; Charlotteville, north-east Tobago

Plate 9 Coral spawning monitoring with dive volunteers.

Feedback from the coral spawning workshops indicated interest in volunteering on coral spawning dives. The MARIN team was joined by volunteers for all spawning dives, including dive masters/ instructors from the Department of Marine Resources and Fisheries (DMRF), THA, dive tour operators (Frontier Divers), dive clubs (ASJA Boy's diving and conservation club), NGOs - SpeSeas, Environmental Research Institute of Charlotteville (ERIC), and Speyside Eco Park Rangers (SEMPR) (Plate 9). However, considerations need to be made for students and individuals without dive insurance and limited experience to ensure safety.

Considerations for management and restoration

The resilience and vulnerability assessments conducted during the pilot, along with several previous monitoring reports and research studies on Tobago reef health and recovery (Buglass et al. 2016; Alemu and Mallela 2021) all reveal that many sites may have slow or even impaired natural recovery, considering the low levels of coral recruitment. Limited hard coral repopulation means that many sites across Tobago, require some intervention in coral restoration to boost coral populations in the short term. However, existing ecological conditions and human impacts may place some sites in a better position for coral survivorship from restoration. Other sites may require targeted stress-reduction strategies of chronic issues, such as water quality, seasonal sediment run off that overlaps with spawning, disease outbreaks, and even tourism activities to improve the condition of the reef to a point where restoration is feasible.

Coral survivorship is a key measure of restoration success, and is dependent on the biophysical state (reef connectivity, oceanographic influence, geomorphology and watershed influence), disturbance history, existing management context in addition to its ecological resilience and projected exposure (Table 3). Many of these biophysical factors for Tobago have not been investigated in this study, but can be inferred from previous studies and even from field experiences. The Reefs at Risk (Burke et al 2008) assessment for the Caribbean estimated that most sites around Tobago have a high threat of overfishing. While this study shows relatively higher fish biomass in the north-eastern sites, most reef sites lacked large commercial species or top predators, and this has been so since the nineties (IMA 2000). With respect to land-based sources of pollution, studies showed higher nutrient pollution in the south west, especially in areas surrounding the Buccoo Reef complex and downstream sites because of watershed–driven eutrophication from sewage discharge (IMA 1994; Lapointe et al. 2010b). Higher sedimentation of fine terrigenous sediment has been noted to be relatively higher along the Caribbean coast, and Speyside with its steeper watershed (Buglass et al. 2016). However, less is known about the seasonal timing of high sediment influx which may significantly impact coral spawning and recruitment events. There is little information on the nearshore oceanography, including reef connectivity to inform management/ restoration strategies.

The management context, such as effective policies, programmes or projects, and even existing restoration activities, and current or future implementations, should be weighed in restoration planning and design. The Buccoo Reef marine protected area (MPA), for example, is the only legislated MPA. However, without enforced management it is a susceptible to degradation from high levels of tourism and fishing activities. That being said, there is some potential management in the future.

With all information gathered, suitable interventions in management, site prioritisation for restoration and restoration strategies can be decided upon using a semi-quantitative method to weigh potential survivorship success. While data will be used to inform the decision-making process, it is key for stakeholders to be involved to give perspective at every step.

Table 3 List of factors to be considered in the decision-making of site selection for targeted management and restoration strategies compiled from pilot findings and previous studies

	Coral Reef Locations, Tobago					
	Buccoo MPA	SW Tobago	Speyside	Charlotteville	Caribbean Coast	reference
Human impact Context						
Watershed pollution threat	Low	Low	Moderate	Moderate	Unknown	(Burke and Maidens 2004)
Coastal development threat	High	High	Moderate	Moderate	Unknown	(Burke and Maidens 2004)
Overfishing threat	High	High	High	High	High	(Burke and Maidens 2004)
Tourism use	High	High	Moderate	Moderate	Low	Personal observation
Biophysical Context						
Oceanography	Sheltered environment. Wave/ current predominantly from the northeast	Mt Irvine - Wave/ current predominantly from the northeast. South coast, seasonal exposed, Current west to east.	Semi-exposed. High current flow. More information needed	Sheltered	Wave/ current predominantly from the northeast. More information needed	Chollett et al. 2012; SWIL 2022
Geomorphology	Well-developed fringing reef complex – forereef, backreef and lagoon	Shallow fringing	Deep fringing along coast and offshore islands	Shallow fringing	Fringing reefs, spur and groove reefs at Culloden/ Plymouth	
Ecological connectivity	Unknown	Unknown	Unknown	Unknown	Unknown	
Bleaching history (2005)	High (>85 %)	High (>85 %)	Low (<20 %)	High (> 85 %)	High (> 85 %)	(O'Farrell and Day 2006) (88 sites around Tobago)
Bleaching history (2010)	Moderate	Unknown	High	Unknown	Moderate	(Alemu I and Clement 2014)
Bleaching risk (ASB RCP 8.5)	Moderate to low	Moderate to low	Moderate to low	Low	Moderate to low	Hooidonk et al 2016
Disease	Moderate to low	Moderate to high	Moderate to high	Moderate to low	Moderate to low	Ganase (in prep)
Ocean acidification	Unknown	Unknown	Unknown	Unknown	Unknown	
Sea-level rise	High (low lying coasts)	High (low lying coasts)	Low	Low	Low	Need more information
Storm surge	High (low lying coasts) (low lying coasts)	High	Low	Low	Low	
Sediment Run off	Unknown	Unknown	Unknown	Unknown	Unknown	
Relative resilience	Buccoo Western - Medium to high; Buccoo Outer (2020) - Medium to high	Flying Reef - Low; Mt Irvine - High	Angel Reef - Medium to low; Blackjack Hole (2020) - Medium to High	Booby Island - Medium to high	Castara (2020) - Medium to high; Culloden - Medium to low; Plymouth - Low	Ganase (in prep), pilot study
Climate vulnerability	Buccoo Western - Medium to low; Buccoo Outer - High	Flying Reef - High; Mt Irvine - Medium to low	Angel Reef - Medium to high Blackjack Hole (2020) - Medium to low	Booby Island - Medium to low	Castara (2020) - Medium to high; Culloden - Medium to high; Plymouth - High	Ganase (in prep), pilot study
Management context						
Government policies & Programmes	Limited and ineffective Policy in draft	None	MPA draft, planned management	MPA draft, planned management	None	
Watershed management	None	None	None	None	None	
Fisheries management	None	None	None	None	None	
Zonation priority	High	Moderate	High	Moderate	Low	
Restoration site priority	Buccoo Western	Mt Irvine	Blackjack Hole	Booby Island	Castara	Ganase (in prep), pilot study

Ongoing and future research to inform management and restoration

Research into improving mechanisms for management and restoration is iterative. Here are some potential research considerations coming out of the pilot:

- Mechanisms to boost reef grazer population (sea urchins and fish herbivores, should be considered). Sea urchins are known to graze the competitive turf algae and peysonnelid algal crusts (that competes with other coralline algae that promote coral recruitment; Stockton and Edmunds 2021). In conjunction with steps to improve water quality, especially in the south-west Tobago
- Better models for projecting climate change exposures at higher resolutions and for a range of climate scenarios.
- Investigations of reef sediment loads, especially during the rainy season, which overlap with coral spawning and recruitment activities.
- Investigating reef connectivity to determine source and sink sites for reseeding but also assess vulnerability to disease outbreaks etc.
- Monitoring for disease prevalence and building capacity for disease management in Tobago especially with sites with greater susceptibility (Speyside and south-coast reefs).
- Wider windows of observation for spawning of coral species not observed.
- Post spawning processes, such as fertilisation, larval settlement (cues) and survival contribute to the overall success of coral reproduction and should be investigated in detail for Tobago (Szmant 1986). This can be done through trial restoration with controlled fertilisation experiment and settlement trials to inform on coral restoration strategies.

Applying coral restoration to Tobago

Outcomes of the pilot study, along with existing IMA research and previous literature were used to inform the following recommendation of restoration planning and implementation strategies for Tobago. The planning for Tobago follows the steps of Shaver et al. (2020) and uses the results of the MARIN Tobago, coral reef scientific report (supplementary document).

Tobago planning considerations (steps 1 - 4):

The suggested planning steps by Shaver et al. (2020) follows a broad proposed goal for Tobago's coral reefs. Such a goal is likely to change with stakeholder consultation and altered to include other restoration goals.

GOAL: To **mitigate declines in coral populations** that provide **critical habitat structure** to Tobago's reefs, thereby **preserving biodiversity** and **increasing coral resilience** against **climate change**.

(1) Set goal and geographic focus for Tobago:

1. Geomorphology - All reefs are fringing reefs, however Buccoo Reef has an extensive sheltered reef area with back reef, lagoon and associated seagrass and mangroves. Speyside reefs - Angel Reef and Blackjack Hole are fringing reefs occurring on offshore islands.
2. Historical state – Several reefs across Tobago have been impacted by coral bleaching in 2005 and 2010 (Table 3). Chronic issues include poor wastewater management

and nutrient pollution with greater waste pollution in the south west associated with higher populations and coastal development, but greater sedimentation risk along the Caribbean coast and north-east Tobago. High risk of overfishing across all sites, but with relatively higher herbivore biomass in north-east Tobago (Angel Reef, Booby Island, and Blackjack Hole (Ganase and Lochan, in prep).

3. Current ecological state – 2022 pilot study and previous studies reveal critically low recruitment densities and a predominance of turf algae on the reefs. However, most sites fare better with respect to hard coral cover and/ or coral diversity (Mt Irvine, Buccoo Western, Booby Island, Angel Reef). A high coral disease incidence at Angel Reef, despite having high herbivore abundance and coral recruitment is a concern. Flying Reef had the lowest hard coral cover, coral recruit density, herbivore biomass and absence of algae. Previous resilience assessments to be considered at this point, such as Castara, Blackjack Hole and Culloden reefs (Ganase et al, in prep).

4. Reef resilience - Resilience of pilot sites using the following indicators: coral diversity, hard coral cover, herbivore biomass, algae cover, coral disease and coral recruitment revealed that Mt Irvine has the highest relative resilience, followed by Buccoo Western and Booby Island with medium to high resilience, then Angel Reef with medium to low resilience. Flying Reef had the lowest relative resilience. Previous assessment in 2020 highlighted Castara, along the Caribbean coast, and Blackjack Hole in Speyside as having medium to high resilience scores (Ganase et al, in prep.)

5. Exposure to climate change - The projected onset of annual severe bleaching (ASB) for Tobago under worst case scenario (RCP 8.5) showed that most reef sites are likely to experience ASB from as early as 2046, except Booby Island and Angel Reef which are likely to experience ASB 5 – 10 years later.

6. Reef connectivity - Currently lack this data. Reef connectivity is necessary to determine natural source and sink sites, as well as assess upstream drivers and downstream impacts.

7. Management state - Tobago has one legislated marine protected area, but there is no active management of marine ecosystems in Tobago. Strategies to advocate for the approval and implementation of polices, such as the Integrated Coastal Zone Management Policy and management plans for sensitive marine areas will boost restoration success. There has been considerable work in drafting some plans and designations that will support management at the national and community level:

    (i) Buccoo Reef Marine Park Management Plan

    (ii) Speyside Management Plan (2002)

    (iii) North-east Tobago Marine Protected Area Plan (IFPAMTT)

    (iv) UNSECO, Man, and the Biosphere Designation

8. Stakeholder engagement - Stakeholders essential to inform decision-making include technical experts, scientists, engineers, community members, private sector, NGOs and government. During the pilot phase, IMA conducted a number of stakeholder engagements to introduce the concept of marine restoration in Tobago and to identify the existing stakeholders. Most stakeholders that attended were scientists, conservationists, business owners and government representatives. More effort to include communities

adjacent to potential restoration sites is required to assess the socio-economic use and cultural value.

(2) Identify, prioritise and select sites

1. Relevance to Restoration Goal: Buccoo Reef is an MPA, houses high biodiversity and its reef structure is critical for coastal protection. Other sites such as Mt Irvine and Booby Island (relatively higher resilience scores and therefore relatively lower climate vulnerability), where restoration can potentially boost their populations and build resilience, even with limited management.

2. Potential to Improve Conditions - Higher herbivore biomass will assist in the restoration especially at sites with lower proximity to coastal development and run off. While Mt Irvine Reef has the highest relative resilience, Booby Island, Angel Reef and Blackjack Hole (2020 assessment; Ganase et al. in prep.) have relatively higher herbivore biomass scores. Angel Reef and Blackjack Hole are also relatively farther offshore. However, Angel Reef is currently impacted by coral disease. Buccoo Western is also located farther offshore along the Buccoo Reef but has lower herbivore biomass.

3. Coral Survival - The likelihood of coral survival is based on the vulnerability of reef to future (climate change) disturbance. Climate change vulnerability was assessed for the pilot sites. Three sites - Buccoo Western, Booby Island and Mt Irvine - had medium to low vulnerability to annual severe bleaching, while Angel Reef had medium to high vulnerability and Flying Reef had high vulnerability. For local impacts, resource use and influence is generally higher in the south west (Mt Irvine, Buccoo Western and Flying Reef).

Final of **priority sites** include **Mt Irvine, Booby Island, Buccoo Western,** followed by **Blackjack Hole**. Flying Reef and Angel Reef will require additional management interventions to curb disease prevalence and control algae.

(3) Identify, design and select interventions

1. Larval-propagation strategies can be used to preserve biodiversity and increase coral resilience against future disturbances. Larval propagation strategies have been developed and applied to many species common to the forereefs of Tobago.

    (i) Target species - Target species will be based on existing populations with predictable spawning times, and history of restoration success. Candidates for restoration include *Colpophyllia natans, Diploria labyrinthiformis* (pending ascertaining predictable spawning times in 2024) and *Pseudodiploria strigosa.* Expansion to other coral species, with less predictable spawning times, and more technically challenging ex-situ propagation strategies can then be conducted in following years, including *Orbicella faveolata* and *Acropora palmata.*

    (ii) Site area/ depth - Restoration will be conducted in areas within a 100 m^2 of site and focussed on the forereef slope (9 - 12 m) at the same depth at which the coral gametes will be collected. The exception is larval propagation of *Acropora palmata* which will reseed shallower locations (< 5 m) where they naturally occur. In-situ CRIBs will be used in absence of ex-situ rearing tanks. However, small-scaled ex-situ set up should be trialled.

2. Coral gardening can be used to restore ecological function and structure, especially of the branching corals that were lost along the shallow reef flats of Buccoo Reef (Laydoo 1984, 1985). The use of asexual propagation methods may be conducted for faster coral growth and structural formation.

    (i) Target species - *Acropora palmata* (Johnson et al. 2011)

    (ii) Site area/ depth - ~ 100 m^2, depth less than 5 m.

    (iii) Nursery sites - Likely to be in Bon Accord Lagoon for priority restoration in the south-west Tobago, followed by Charlotteville in north-east Tobago

(4) Develop a restoration action plan

1. SMART (specific, measurable, achievable, relevant, and time-bound) objectives - For example: Within 10 years, increase the populations of at least five of the critically important coral species (*Colpophyllia natans, Pseudodiploria strigosa, Diploria labyrinthiformis, Orbicella faveolata, Acropora palmata*) by 10 – 30 % on at least three reef sites (Booby Island, Blackjack Hole, Mt Irvine Reef and Buccoo Western) using larval-propagations strategies that increase the genetic diversity and resilience against climate change impacts.

2. Implementation logistics:

    (i) Timeline - At least five years for implementation and up to ten years of monitoring to assess ecological function and adaptation

    (ii) Requirements – Permits, permissions etc

    (iii) Resources – Personnel, equipment and funds

    (iv) Inclusion - Use of community groups, NGOs, students to assist in the monitoring (through the Marine Resilience Network).

3. Evaluation and performance metrics:

    (i) Improved ecological function or at least mitigation in coral population decline and biodiversity – Regular assessments of the following metrics to be conducted: coral abundance, size and cover, survival and diversity (species and genotypic diversity) (Goergen et al. 2020).

    (ii) Improvements to reef function - Reef structural complexity, fish community and habitat quality

Tobago restoration implementation (steps for 5 and 6):

(5) Implement restoration strategies

1. Action Plans must include players of the Marine Resilience Network, resources and timelines and should be reviewed annually.

(6) Monitor and evaluate– Evaluating success of the restoration is largely dependent on the goal of the restoration. For the restoration of ecological function and resilience, baseline/ historical information should be used where possible as a reference, as well as a control comparison (Goergen et al. 2020). The IMA has long-term data for proposed restoration site to facilitate such

assessments. For building climate resilience, measurements of survival, recovery rates following acute thermal stress events may be indicative of coral adaptation (Goergen et al. 2020). Here are suggestions from Goergen et al (2020) that are applicable to Tobago:

1. Success in ecological restoration:
    - (i) Similar or increase in coral assemblage species
    - (ii) Increase in coral species abundance and cover
    - (iii) Continued development by coral population (natural colonisation)
    - (iv) Increase in reef structural complexity
2. Success in socio-economic resilience:
    - (i) Increase the members and the utilisation of the Marine Resilience Network
    - (ii) Number of persons skilled in restoration
    - (iii) Increase in community involvement
    - (iv) Increase in awareness
    - (v) Implementation of policies, legislation and plans.
3. Success in climate adaptation:
    - (i) Survival rates against disturbance
    - (ii) Lower occurrence to coral disease
    - (iii) Diversity of coral genotypes
    - (iv) Improved coastal protection (Buccoo Reef) measured by long-term changes in beach accretion and erosion rates (IMA monitoring of coastal processes).

Upscaling and restoration costs

Coral reef restoration is expensive and labour intensive. This section provides a basic understanding of the cost of implementing different restoration strategies in Tobago. The restoration cost is measured for a single restoration activity that considers the restoration of one species at one site and one point of time (Table 4). The activity starts with the nursery preparation, followed by collection and rearing and ends with coral outplanting.

Monitoring and evaluation costs are separate from the restoration costs. The expenses are divided into three main cost categories: equipment, personnel and logistics. The equipment cost focuses only on the materials needed for construction, outplanting and monitoring (Table 4). Personnel cost refers to salaries of a minimum of three staff members - two experts in marine ecology and one technician. Logistical costs include fuel, boat rental, dive tank rentals and miscellaneous items. All methods include long-term monitoring which can be conducted by the same expert team or trained personnel or partner entities. Likely variations in any of three cost categories may result from changes in the personnel numbers and expertise level, the use of alternative materials, and the compilation of

activities (Table 4). Upscaling restoration (multiple species and multiple sites), while very important, is labour intensive, and incurs a high cost in development, as well as long-term monitoring. Therefore, it is critical that implemented strategies can be properly sustained. Varying environmental conditions also play a key role.

Asexual restoration by coral gardening

Cost

The costs consider two nursery strategy options (1) table nursery and (2) tree nursery. Each option is dependent on the environmental conditions of the nursery. The total cost of a single coral gardening restoration activity ranges ~55,000 TTD (coral tree nursery) to 69,000 TTD (table nursery method) (Table 4). A list of the basic equipment for coral gardening can be found in Table 5.

Timeline

The initial activities consist of the construction and deployment of the nurseries (one week), followed by the collection of fragments. The nursery will be left in situ for a couple weeks to allow for leaching of any material from the PVC and steel fittings as these can affect the corals. Populating the nurseries with fragments of target species can be conducted over four days. Monitoring of the nursery will be conducted over four days at least every two months. Monitoring of the nursery will entail cleaning and carefully scrubbing away algae and other organisms that may colonise the artificial structures. Measurements and photographs of the fragments should be recorded. Fragment health and mortality rates should be recorded. Any necessary maintenance of the nursery should be done. After six to twelve months depending on the branching species used and conditions of the nursery, corals will be outplanted and monitored every six months (Lirman 2000; Bay Islands Reef Restoration, Coral Restoration Foundation™). Corals from the same parent will be outplanted in clusters. Fragments will be attached to the reef in an orientation where the least amount of live tissue is in contact with the substrate's surface (Figure 14 and 15). A checklist of the minimum equipment required for coral nurseries can be found in Table 5.

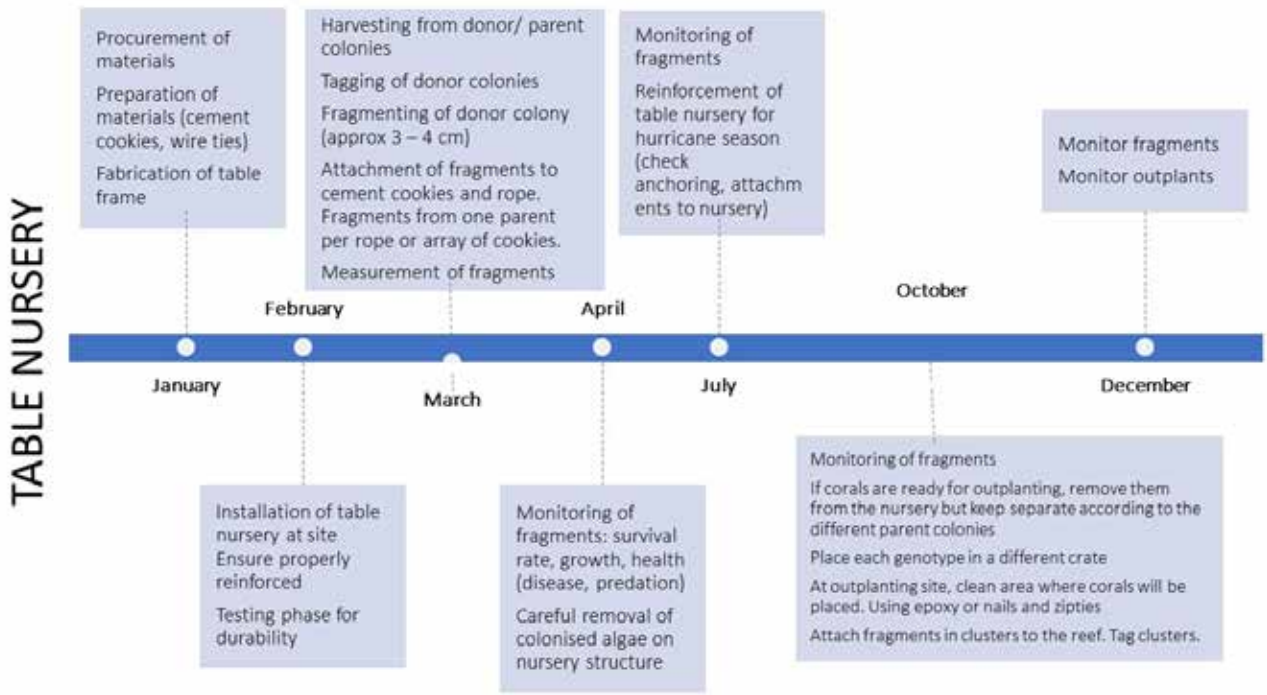


Figure 14 Table nursery timeline of restoration activities

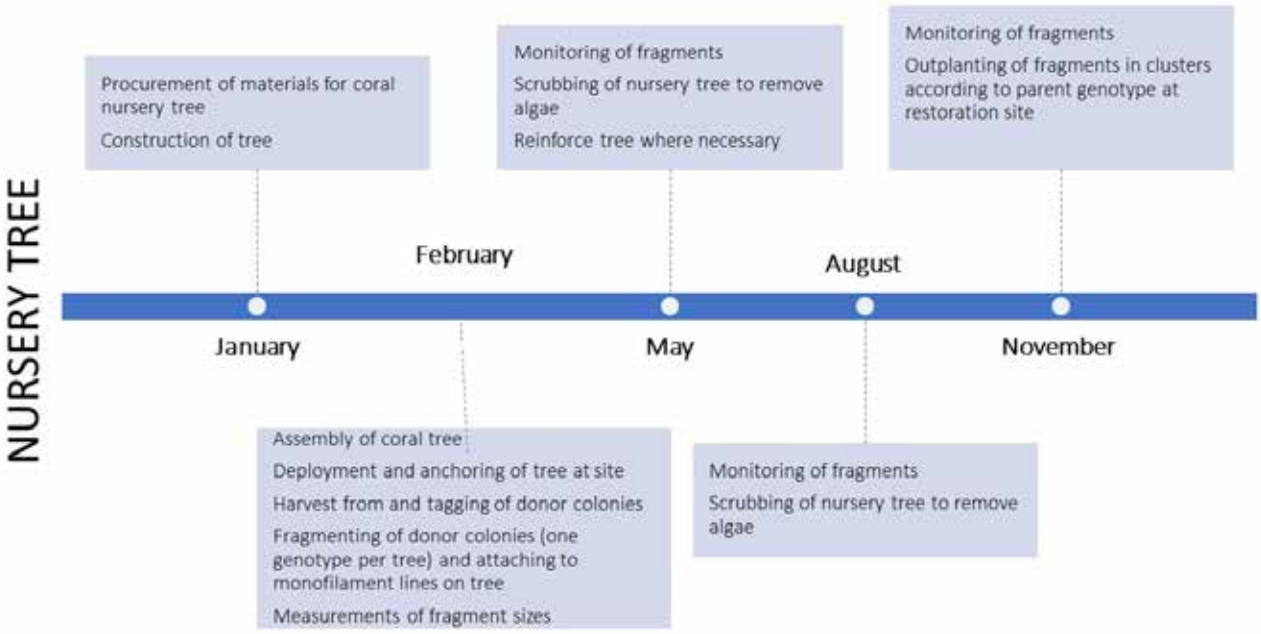


Figure 15 Tree nursery timeline of restoration activities

Larval propagation

Costs

The total cost of one larval propagation activity is ~ 306,000 TTD (Table 4) and is facilitated by SECORE International. This method involves the four main parts – conditioning of settlement tiles, set up of ex-situ tanks or in-situ coral rearing in-situ basins (CRIBS - designed by SECORE International), collection / fertilisation of gametes during spawning and seeding on tiles, outplanting and monitoring. One month in advance of the coral spawning, recruitment tiles will be conditioned to preferred coralline algae. Two days prior to the spawning window, the CRIBs will be set up and deployed with the conditioned tiles. Depending on the species, the relevant spawning window is ~ 4 to 5 days during which time gametes of the species are collected for fertilisation. Once gametes are collected and cross-fertilisations are conducted, the resulting larvae are placed inside the CRIB which contains hundreds of seeding units to encourage coral larval settlement. The CRIB will be carefully monitored daily to determine the stage where larvae are no longer swimming in the water column but are beginning to settle on the seeding units. Over two to three weeks, CRIBs will be maintained and cleaned.

After two to three weeks, seeding units will be ready for outplanting, once an average yield has been recorded. Yield refers to the proportion of outplanted seeding units that retains at least one live coral at a given time. Once ready for outplanting, crates would be carefully removed from the CRIB. Seeding units will be outplanted at the respective reef sites by wedging the unit into the reef ensuring the coral settlers remain protected and undisturbed. Outplanted seeding units will be monitored once a year (Figure 16). A checklist of the minimum equipment required for larval propagation can be found in Table 5.

Figure 16 Larval-propagation restoration timeline of activities

Table 4 Outline of budget needed for each coral restoration activity

Activity (one species, one site, one collection and one outplanting)	Duration of activity/ days	Equipment Cost	Personnel Cost	Logistics Cost	Total Cost (TTD)
Table nursery					
Construction and deployment	3	5,500	8,000	14,000	22,500
Population	2	10,000	5,500	12,000	23,500
Outplanting	3	4,000	8,000	16,000	23,000
Coral tree					
Construction and deployment	3	6,000	8,000	12,000	22,000
Population	2	500	8,000	12,000	16,500
Outplanting	3	3,500	5,000	10,000	16,500
Microfragmentation					
Collection, fragging and outplanting with ex-situ set-up	4	48,000	10,000	18,000	69,000
Collection, fragging and outplanting without ex-situ setup	4	14,000	10,000	18,000	35,000
Larval propagation					
Construction of gamete collection nets	2	4,500			
CRIB set up	1	150,000	70,000	84,000	261,000
Gamete collection and cross fertilizations	5	8,000	See CRIB setup	See CRIB setup	
Monitoring of larvae and CRIB maintenance	20	25,000	See CRIB setup	See CRIB setup	
Outplanting of substrates	3	5,000	See CRIB setup	See CRIB setup	
Breakdown of CRIB	1	2,500	See CRIB setup	See CRIB setup	
Substrate stabilisation					
Deployment of stabilisation mechanism	3	7,000	9,000	10,000	26,000
Monitoring Costs					
Long term maintenance and monitoring of nurseries	4 days every 2-3 months	1,000	10,000	11,000	22,000
Long term monitoring of outplants	5 days once a year	2,000	13,000	13,000	28,000
Other monitoring equipment					
SCUBA gear and other diving materials					45,000
Olympus TG6 underwater camera and housing					6,000

Table notes:

1. *For personnel, two scientists and one technical support were assumed for budgeting purposes. This can be reduced to one scientist and one technical support, although it may be necessary to extend the duration of the trip by at least a day.*
2. *Activities were budgeted separately to derive cost estimates; however, coordination of field work may facilitate the possibility to combine activities. For example, all nursery deployments on the same trip or monitoring of nurseries and outplants on the same trip.*
3. *Dive gear and camera gear were kept separate as they are used in each activity but would inflate the actual cost of the individual activity.*
4. *Using alternatives to the equipment listed can also reduce cost. For example, inclusion of purchase of microscope and cyanoacrylate gel significantly increase cost of activity.*
5. *Miscellaneous funds were budgeted in "Logistics". This can be transferred to "Equipment" if necessary.*

6. *This budget accounts for the construction of one table nursery and one coral tree.*

7. *"CRIB setup" refers to the first of five activities that are done for the larval propagation field work trip. However, the Personnel and Logistical costs listed next to "CRIB setup" cover this activity as well as the other activities listed hence "See CRIB setup" in the personnel and equipment columns.*

Table 5 Checklist of minimum equipment needed for the different coral restoration strategies

Item	Table nursery	Coral tree	Micro-fragmentation	Larval Propagation	Substrate stabilisation	Outplanting	Monitoring
16mm steel rods 30 m long	x						
Circular saw	x						
9.5mm thick rope/ft	x						
PVC coated chicken wire	x						
Plastic mesh	x						
Zip ties	x	x	x	x	x	x	x
Sledgehammer	x	x	x		x		
Scrub brushes	x	x	x		x	x	x
Toothbrushes	x	x	x			x	x
Monofilament line	x	x					
Cyanoacrylate gel	x		x				
Reef Safe Epoxy Putty	x		x			x	
Scissors	x	x	x	x	x	x	x
Crates	x	x	x	x		x	
Cement cookies	x		x			x	
Sikacrete	x		x			x	
Type II cement	x		x			x	
Hammers	x	x	x	x	x	x	x
Nails	x	x	x	x	x	x	x
Scrub brushes	x	x	x			x	x
Toothbrushes	x	x	x			x	x
Wire brush	x						x
Tags	x	x	x	x		x	x
Slate and pencils	x	x	x	x	x	x	x
Plastic baskets	x	x	x			x	
Buckets	x	x	x	x		x	
19mm PVC for central column of coral tree		x					
PVC piping for arms		x					
PVC connectors		x					
Metal crimps		x					
Shears	x	x	x				
Mooring line		x		x			
Anchor (duckbill)		x					
PVC glue		x					
Buoys		x				x	x
PVC cutter		x					
Crimper		x					
Measuring tape (tailor)				x			x

Ruler							x
Cordless drill		x					
Gryphon diamond blade saw			x				
Coral cookies- cement							
Nally bins			x	x			
Pneumatic drill			x				
10” galvanized nails			x				
Ex-situ system			x	x			
Dive kits	x	x	x	x	x	x	x
Dive torches				x			
Waterproof paper							x
Dive Buoy	x	x	x	x	x	x	x
Dive strobes	x						
Dive Computer	x	x	x	x	x	x	x
Camera and housing						x	x
Microscope				x			x
Heavy duty gloves	x				x		
Measuring tapes 50m	x		x		x	x	x
Mesh bags	x	x	x	x	x	x	x
CRIBS				x			
Stainless steel carabiners	x	x	x	x	x	x	x
Nylon thread				x			
Net collector fabric				x			
Reflective tape				x			
Pool noodles				x			
Sinkers				x			
Funnels				x			
Gorilla glue	x	x	x	x	x	x	x
50ml tubes				x			
Glue gun				x			
Glue sticks				x			
Potable water jugs				x			
Aquarium filters socks				x			
Gravy fat separators				x			
Plastic transfer pipettes				x			
Wash bottles				x			
Petri dishes				x			
Bleach				x			
Sodium thiosulphate				x			
Dawn soap				x			
Disposable droppers				x			
Blue lights (yellow glasses)				x			x
Tally counter				x			
Chisel	x	x	x				
Quadrats						x	x

Critique framework for seagrass management, conservation and restoration in Tobago

Developing a practical framework for applying seagrass conservation and restoration is critical. In light of the United Nation's 2023 Agenda for Sustainable Development, a repeatable, critique framework has been developed to allow countries to assess four main categories - Monitoring, Management, Protection and Restoration – for current efforts for seagrass conservation and restoration using a standardised scoring system (Strachan et al. 2022) (Figure 17). We applied the framework to Tobago and scored using existing knowledge of the four categories (Table 6). While Tobago scores favourably for monitoring and research activities (score = 5), significant work is needed to improve the scores for Management and Restoration, reflected by the little activities undertaken (Table 7). Existing legislation for protection, and restoration efforts in the Bon Accord Lagoon scored *3*, which is moderate (Table 7). To truly benefit from these habitats and build ecological resilience, future activities needed to increase the overall score of *24/40* must be focussed on building public awareness on the value of seagrass, designated areas of protections where seagrass are a targeted for conservation. Furthermore, national action plans include sustainable strategies for seagrass management and restoration (Table 6).

It is critical to note that these factors: Monitoring, Management, Protection and Restoration do not operate in isolation. Monitoring will be used to inform Protection and Management strategies, and to evaluate their effectiveness. While this report focusses on restoration approaches for seagrasses, effective coastal and marine management of sensitive marine ecosystems, including seagrasses, is key to successful restoration.

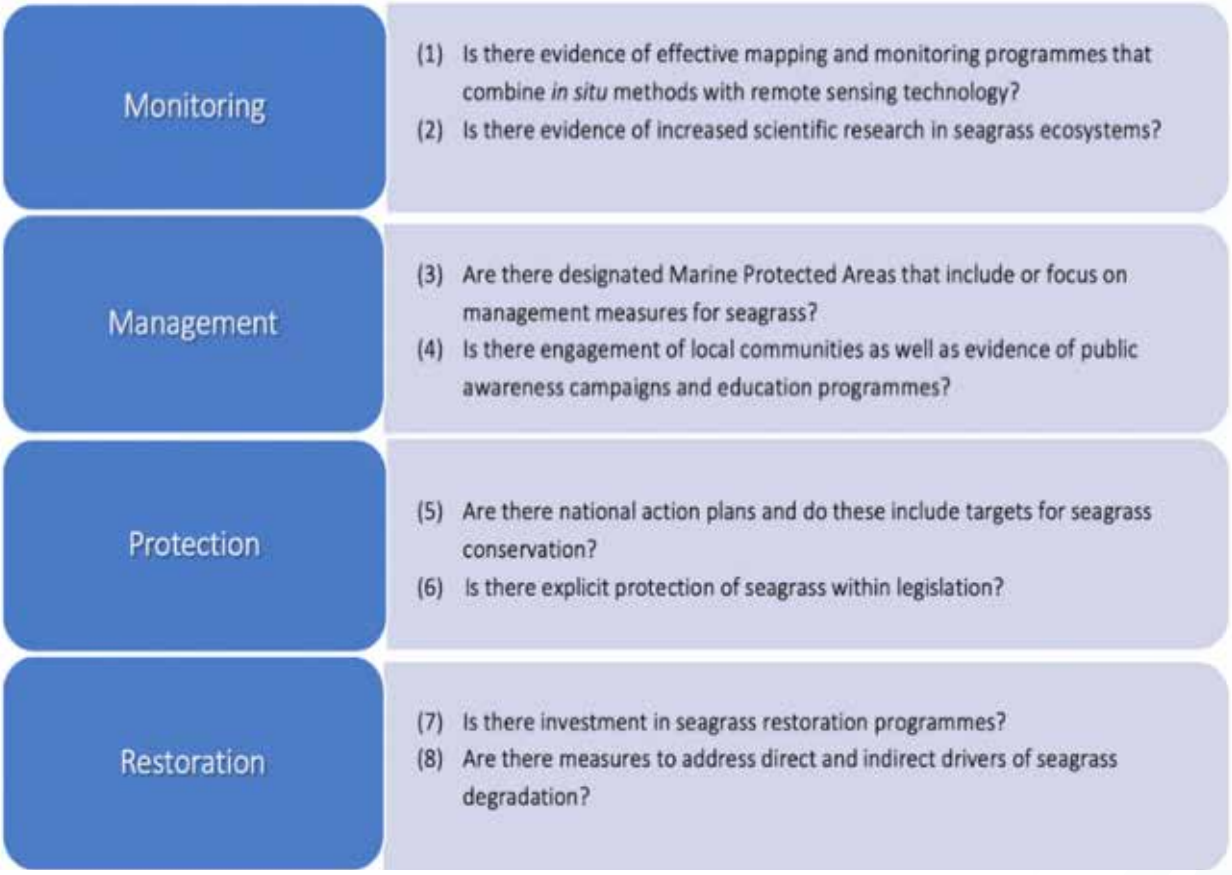


Figure 17 Critique framework developed from the UNEP recommended management measures and tools (Strachan et al., 2022)

Table 6 Criteria of the scoring system ranging from 1 to 5 with examples commensurate with the grading sourced from Stachan et al., 2022

1	2	3	4	5
No Evidence	Limited evidence; major gaps	Moderate evidence; some gaps	Well evidenced	Significant evidence; excellent examples of best practice
Monitoring				
• No monitoring programmes in place • Extent of seagrass is not known No accurate or recent mapping of seagrass • Limited research being carried out in this area; small number of publications	• Some monitoring for specific research studies, small scale or ad hoc surveys, may be reliant on short-term funding • Relatively basic monitoring methods and techniques • Extent of seagrass is not known with no accurate or recent mapping of seagrass • Some research being conducted and number of publications varies between years, no clear trend.	• More than one mapping and monitoring programme • Evidence of monitoring but not sustained over long periods of time • Monitoring methods of good standard • Extent of seagrass is somewhat known with evidence of mapping • Ongoing research, research base indicating a steady upward trend	• Various monitoring programmes and studies ongoing • Up-to-date techniques to map and monitor, with a combination of methods (in situ and remote sensing) • Significant ongoing research, research base indicating a clear upward trend	• Highly effective mapping and a long time series seagrass monitoring programme • Consistent water quality monitoring Most up-to-date techniques to map and monitor that combine in situ methods with remote sensing technology Use of global seagrass monitoring networks Significant research, research base increasing exponentially
Management				
No management measures specific to seagrass habitats No public awareness campaigns and education programmes relating to seagrass	Little evidence of management measures specific to seagrass habitats Limited public awareness campaigns and education programmes relating to seagrass	Management measures in place relating to seagrass habitats A number of public awareness campaigns and education programmes	Designated MPAs that include seagrass management measures •Engagement of local communities Well-established public awareness campaigns and education programmes	Designated MPAs that include seagrass management measures and include targets and actions for seagrass habitats •Engagement of local communities •Extensive and well-established public awareness campaigns and education programmes
Protection				
No national action plan or targets for marine habitats No seagrass protection in legislation or policy	National action plan for marine habitats but no targets for seagrass Limited seagrass protection in legislation or policy	National action plans for marine habitats: seagrass species listed in plans Seagrass protection through managed areas or legislation eg. protection to benthic habitats	• National action plans for marine habitats: seagrass species listed with targets for conservation Seagrass protection through managed areas or legislation specifically relating to seagrass	Well established national action plans for marine habitats: seagrass species listed and targets for seagrass conservation and management Explicit protection of seagrass within managed areas and legislation
Restoration				
No seagrass restoration programmes No evidence of plans or proposals for seagrass restoration No measures taken to address drivers of seagrass degradation, through international frameworks and directives	Plans and proposed research looking into the possibility of restoration of seagrass meadows with feasibility studies Some measures taken to address drivers of seagrass degradation, through international and national frameworks and directives	Current research looking into ecosystem restoration of seagrass meadows Seagrass restoration trials and projects may have been undertaken in some cases with varying levels of success Measures in place to address drivers of seagrass degradation with local consideration as well as international and national frameworks and directives	Some investment in seagrass restoration programmes Seagrass restoration trials and projects have been undertaken Measures in place to address drivers: of seagrass degradation with local consideration as well as international and national frameworks and directives	Large amount of investment in seagrass restoration programmes Multiple successful seagrass restoration projects have been undertaken Measures in place to address drivers of seagrass degradation explicitly considering seagrass habitats

Table 7 Tobago's scores based on the critique framework and scoring criteria as described by Strachan et al. (2022). Colours show the scoring 1–5, (1) red: no evidence; (2) pink: limited evidence; major gaps, (3) orange: moderate evidence; some gaps, (4) light green: well evidenced, and (5) dark green; significant evidence; excellent examples of best practice

	Country	
Case study	Tobago	Tobago Score
Monitoring		
(1) Is there evidence of effective mapping and monitoring programmes that combine in situ methods with remote sensing technology?	Long term monitoring of seagrass in Tobago is well established and is still conducted by the Institute of Marine Affairs (IMA). This includes the use of in-situ methods as well as remote sensing. Water quality testing conducted consistently. Strong baseline data available.	**5**
(2) Is there evidence of increased scientific research in seagrass ecosystems?	There has been publishing of seagrass research in scientific journals.	**4**
Management		
(3) Are there designated Marine Protected areas that include or focus on management measures for seagrass?	While seagrass beds are covered under the National Policy and Programmes on Wetland Conservation for Trinidad and Tobago (2002), only one designated Protected Area in T&T include seagrass beds. Little evidence of management specific to seagrass ecosystem.	**2**
(4) Is there engagement of local communities as well as evidence of public awareness campaigns and educational programmes?	IMA has outreach programmes to raise awareness on the conservation of seagrass ecosystem, but this has limited reach to coastal communities. Attempts underway to amplify seagrass education and community engagement and implement management for seagrass protection.	**2**
Protection		
(5) Are there national action plans and do these include targets for seagrass conservation?	The draft Integrated Coastal Zone Management (ICZM) Framework and Action Plan 2020 has targets for seagrass conservation/ restoration, but this has to be approved by Cabinet.	**3**
(6) Is there explicit protection of seagrasses within legislation?	No existing legislation that explicitly protects seagrass beds. Seagrass beds exist within the Bon Accord Lagoon, which is protected under the Marine Area (Preservation and Enhancement) Act Chapter 37:02 of 1970. The Act does not explicitly speak to seagrass ecosystem, but to the ecosystem complex inclusive of mangrove forests and coral reef.	**2**
Restoration		
(7) Is there investment in seagrass restoration programmes?	There is current research investment for seagrass restoration albeit recent. This involves investigating seagrass restoration through the MARIN Project. Seagrass restoration trials have been attempted which have yielded varying results. Further research being undertaken to improve restoration efforts.	3
(8) Are there measures to address direct and indirect drivers of seagrass degradation?	The formulation of the ICZM Policy is to address direct and indirect drivers of seagrass degradation. The Policy is awaiting approval from the Cabinet of T&T.	3
Total score		**24/40**

Seagrass restoration planning and design

According to Campbell (2002), there are five main considerations when undertaking a seagrass restoration project. These include objective setting, site selection, transplant unit and technique, habitat enhancement (optional) and review of objectives. Decision trees for these factors guide managers along the practicality of their proposed seagrass restoration attempts. Furthermore, van Katwijk et al. (2016) provided additional guidelines for restoration that include: selection of appropriate donor site, spreading of risks, and assessing hydrodynamics. Finally, facilitating community engagement is a critical step and was proposed by Erftemeijer (2020; UNEP-Nairobi Convention/WIOMSA, 2020).

1. **Objective setting**

    - Identify the species to undergo restoration
    - Conduct extensive literature reviews focused on the optimum environmental conditions for species; ideal habitat locations, reproductive and growth strategies, history of disturbance and restoration

2. **Transplant site selection**

    - Historical seagrass growth
    - Similar depth and environmental conditions (eg. substrate, light requirements, water quality, water motion) between donor and transplant sites
    - Habitat suitability model (*if possible*)

3. **Transplant unit and technique**

    - Incorporate literature and empirical data on sexual and vegetative units of the species to be restored

4. **Habitat enhancement**

    - This step is useful to improve the existing conditions to enhance seagrass growth, establishment and survivability

5. **Selection of appropriate donor site**

    - Appropriate traits required for survival, establishment and colonisation of the transplant site (must be adapted to local conditions)
    - Ability to survive long term
    - Close proximity to transplant site to reduce risk of “isolation by distance” (Olsen et al. 2004).
    - Should be taken from populations in similar environmental conditions

6. **Spreading of risks**

    - In wild populations, risk is accommodated by the presence of genetic diversity, phenotypic plasticity and varying life history traits.
    - Improves the research conducted as realistic environmental conditions may alter expected results.
    - Can be done within areas that have different hydrodynamic conditions, transplanting at different depths and proximities and planting during different periods of time (van Katwijk et al. 2016; Erftemeijer 2020).

7. **Assessing hydrodynamics: optimising techniques and accounting for ecosystem engineering effects**

    - Transplantation success is often affected by hydrodynamic challenges or disturbances to the outplants (van Katwijk et al. 2016).
    - Stabilising structures or anchoring techniques may have different impacts in different sites.
    - Loosened materials may increase destruction and mortality in strong currents and strong wave action.

8. **Timeline of restoration activities**

    - Periods where restoration activities must be carefully planned, such as replanting in dry season, avoiding turbulent seas and turbid conditions

9. **Review of objectives**

    - Understand all potential outcomes of objectives and develop a restoration strategy plan that supported by research
    - Create a budget to highlight realistic funding targets

10. **Community inclusion**

    - The empowerment of local communities and resource users to better understand the value of marine ecosystems, specifically seagrasses.
    - Capacity building within the community for more sustainable restoration efforts.

Strategies in seagrass restoration

Seagrass restoration is becoming increasingly important and many restoration attempts have been made over the decades. However, no single model of success has been developed (Campbell 2002). Many modified methods exist that have been used to trial seagrass restoration in various parts of the world and applied to an array of environmental conditions. Restoration attempts in the United States ranges from < 50 to 88 % success in seagrass transplantation (Campbell 2002; Paling et al. 2009; Rezek et al. 2019). In the European region and Australia success is reported in < 22 % of published works with success focusing on 50 % survival and 50 % rhizome extension. According to van Katwijk et al. (2016), an evaluation of 1,786 restoration trials reported estimated seagrass restoration trial survival rates of 37 % overall and 42 % survival for large restorations (>100,000 shoots/ seeds planted) after 22 months. The survival rate of individual planting units has also been estimated at 38 % based on literature analysis (Bayraktarov et al. 2016). Failures of seagrass restoration projects can be attributed to incorrect site selection, incorrect methodology selection, limited propagule supply, poor habitat conditions, algal blooms, physical disturbance, high turbidity and lack of investigation into initial causes of seagrass loss (Campbell 2002; Erftemeijer 2020; Tan et al. 2020). High expenditures, low success rates and high labour intensity are often considered drawbacks to active seagrass restoration (Bayraktarov et al. 2016; Tan et al. 2020). The many trials of seagrasses replanting have resulted in an array of replanting strategies. Here are examples of more commonly used strategies:

Planting unit to use in restoration

In a study conducted in Western Australia using *Phragmites australis*, it was found that use of vegetative rhizomes (31 %) produced better establishment rates than fruiting bodies which had low establishment (< 3 %). This occurred even though *P. australis* exhibits high fruiting body production and fruit longevity (Čuda et al. 2021). Seedling survival however is low. This may be useful to consider when replanting of *Thalassia testudinum,* although more on the patterns of sexual reproduction is needed for Tobago.

Manual restoration methods

Seed based restoration

Manual broadcasting of seeds via the collection and dispersal of seagrass seeds.

1. **Use of hessian bags** - Seeds are collected and placed inside small hessian bags with sediment to facilitate germination and deployed on the substrate (Erftemeijer 2020). In a study conducted by Unsworth et al (2019) in the UK, 24 bags each filled with approximately 100 *Zostera marina* seeds yielded seed success of 3.7% with an average of 2.37 ± 2.41 mature shoots after 10 months.

2. **Buoy-Deployed Seeding (BuDS)** - Restoration plots are set up and reproductive shoots are bagged, attached to buoys and suspended over the restoration plot. Once the seeding process begins, the restoration plots will receive fallen seeds and germination and growth of new seagrasses will occur (Tan et al., 2020). This method has a 1 to 6.9 % success rate in the limited number of trials conducted on one species *Zostera marina*. Additionally, this method is best suited for calm, sheltered areas as seeds may be disturbed and dispersed away from the restoration plots in rough seas (Pickerell et al., 2005; Tan et al., 2020).

Methods without sediment

1. **Anchoring of shoots with metal pins (also known as staple method)** - Seagrass shoots are harvested from the donor site and the sediment is shaken off of the roots and rhizomes. Seagrass material is kept submerged until the planting process. Presence of apical meristems is critical to ensure new growth and colonisation at the restoration site. There should be at least one apical shoot per planting unit with a preference for three shoots per rhizome fragment in *Thalassia spp.* (Erftemeijer 2020). Planting units are then individually tied to U shaped non-treated metal pins (approximately 10 inches long) using biodegradable twine. In Demark, successful restoration has been conducted using this method as scientists were able to restore 1.5 ha with 40,000 shoots (Tan et al. 2020; Lange et al. 2022). An increase in shoot density from 19 to 900 m^2 over two years. This success is also attributed to the corrosion of iron which can enhance the productivity of the area by increasing absorption of phosphorus (Holmer et al. 2005). This method can sometimes be done without pins and planting the shoot directly into the sediment; it is not always successful as shoots can be uprooted by strong wave action (Matheson et al. 2017). In another study conducted by Park and Lee (2007) in Korea, a total of 80 *Zostera* shoots were planted in a 1 m^2 area, in three different sediment types: mud, silt and sand. Survivability was similar in the three substrate types with 60 – 98 % survival. Establishment of transplants took 1 to 2.3 months (Park and Lee, 2007). This method however was very time consuming and required a long period of SCUBA diving to deploy individual pins.

2. **TERFS™ -Transplanting (Zostera) Eelgrass Remotely with Frames System (TERFS) (and modifications)** - This method was developed by Short et al. (2002). Harvested seagrass shoots were attached to wire frames using biodegradable twine and secured onto the seafloor using four bricks per wire frame. This ensured the seagrass is in contact with the sediment but also protect the frames from disturbance during wave action. Metal spikes can also be used to anchor the frames into the sediment. Once the seagrasses become rooted, they can be detached from the frame. This process usually requires monitoring over 3-5 weeks, although this may vary depending on local conditions.

   The framing can be modified with some trials using rubber coated wire or PVC. Use of these materials allow for re-use of the frame in future transplanting (Massachusetts Division of Marine Fisheries, 2006). Reinforced fabric of steel (BRC) frames was used in the pilot study. If lost, the BRC would corrode over a few months thereby reducing the risk of wildlife entrapment if dislodged. The TERFS method is useful as it is low cost and requires little to no use of SCUBA. In the same trial study conducted by Park and Lee, two hundred shoots were planted on a metal frame totaling 1 m^2. This method had a lower survival rate of 58.7-69 % with establishment of outplants taking 2.2 to 2.6 months. This process did experience anchoring challenges although it did take less time for deployment. According to Park and Lee (2007), this method is best suited for large scale restoration as compared to metal pins.

3. **Shoots attached to hessian bags** – The attachment of seagrass shoots to hessian bag material, which is anchored into the seafloor. Hessian bags are used as an organic alternative to metal frames. This method has been applied in Wasini Island, Kenya for a large area of 2.3 ha being restored using *Thalassia hemprichii* with hessian bags as the anchoring mechanism (Erftemeijer 2020).

Methods with sediment

According to van Katwijk et al., (2016), transplantation with sediment results in higher establishment and yields. One major drawback, however, is that coring methods are very labour intensive and heavy making it difficult to transport, especially as seagrass work is often conducted via snorkelling. Coring through thick root systems can be difficult. Additionally, keeping track of donor cores, as well as keeping them separate can also pose a challenge. While the introduction of invasive species through sediment may also be a concern, there is no literature on this to date. Proper biosecurity techniques should be employed when transferring sediment from one location to another.

Replanting methods with sediment were attempted in Venice Italy by Curiel et al. (2003) for *Cymodocea nodosa* and *Zostera marina.* After two growing seasons, both sets of seagrasses showed success rates ranging from 70 to 86 % for both species after 17 months.

Sod method - Removal of a large clump of seagrass using a shovel to be replanted at another site.

Plug method- Use of corers of different diameters to remove cores of seagrasses.

Mechanical restoration methods

These methods involve the use of machinery and are mainly for large scale restoration activities. Additionally, these methods would be best suited to seagrass replanting in intertidal zones, verses sub-tidal environments. Mechanical seed replanting was attempted in Chesapeake Bay to replant *Z. marina* with a 5 - 10% success rate (Orth et al., 2008). This is a similar rate to using hand broadcasting methods for seeds.

Monitoring

A long-term monitoring plan of approximately five years should be implemented. Existing literature highlights the needs for quarterly periodic monitoring in the first year, bi-annual monitoring in the second year, and annual monitoring for subsequent years. This, however, is subject to conditions and the response of restored species being used (Erftemeijer 2020). Monitoring of transplants includes parameters, such as survival, shoot density, aerial coverage, leaf morphology, epiphyte coverage and biomass. At the end of the five years, additional parameters can be monitored for changes in faunal biodiversity within the restoration site, sediment structure and carbon sequestration metrics (Erftemeijer 2020; Gamble et al. 2021).

Selecting a method for Tobago

For Tobago, because of the paucity of existing data on the life cycle of seagrasses, more research is needed in order to conduct restoration based on sexual reproduction.

The trialling of the pin method, TERFS frame/ hessian bag and coring appear to be suitable approaches for the seagrass habitats of Tobago. These allow for use of vegetative propagation of the shoot and have medium to high levels of success. It is key, however, to assess the success of these strategies at different sites and different substrate types to determine the most suitable methodologies for Tobago.

Overview of pilot activities to assess restoration feasibility

OBJECTIVES

The objectives of the feasibility study were as follows:

1. To map and characterise the seagrasses of Bon Accord Lagoon to identify suitable donor sites.
2. To conduct an ecological assessment of seagrass beds in Bon Accord Lagoon, Kilgwyn and La Guira Bay
3. To estimate the carbon stored in the seagrass beds of Bon Accord Lagoon
4. To trial different methodologies for suitability at trial replanting sites
5. To build community engagement during the seagrass replanting process

Full results of the ecological assessment are provided in a supplementary document: MARIN Tobago: Seagrass Scientific Report.

OBJECTIVE #1: To map and characterise the seagrasses of Bon Accord Lagoon to identify suitable donor sites

Mapping, using side scan sonar and satellite imagery, was done to determine the spatial distribution, density and extent of seagrass beds in Bon Accord Lagoon. These activities resulted in the production of a bathymetry and habitat map, which was verified by in-situ spot surveys at several random locations to confirm seagrass occurrence, density and health of the seagrass communities (Figure 18). This information provides the basis for responsible removal of seagrasses.

Outcomes of Objective #1

From the satellite imagery acquired in April 2022, the seagrass beds covered an area of approximately 95.04 ha (Figure 19), including dense (39.92 ha), moderately dense (40.02 ha) and sparse (15.01 ha) areas. The mapping process introduced challenges with respect to differentiating between seagrass and macroalgae species. *Halodule wrightii* had a similar appearance to macroalgae in the mapping and therefore further ground truthing was needed to discern the difference. The mix of *Thalassia testudinum* and *Halodule wrightii* also exhibits a distinct pattern, and further assessment was required for supervised image object classification applicability. Areas with dense healthy beds would be best suited as donor sites, such as along the western margins of the Lagoon, north of No Man's Land and Pigeon Point and within the inner side of the lagoon (Figure 19).

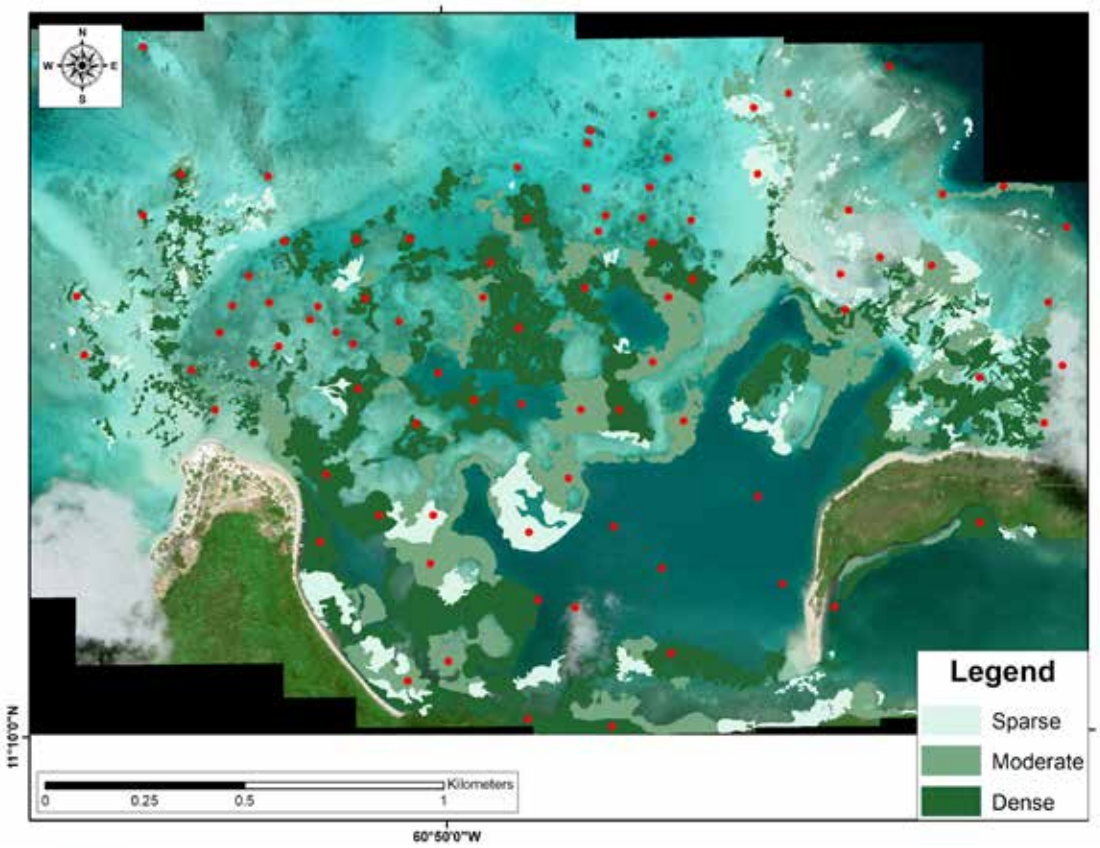


Figure 18 Preliminary Mapping Results and points prior to ground- trothing location in red

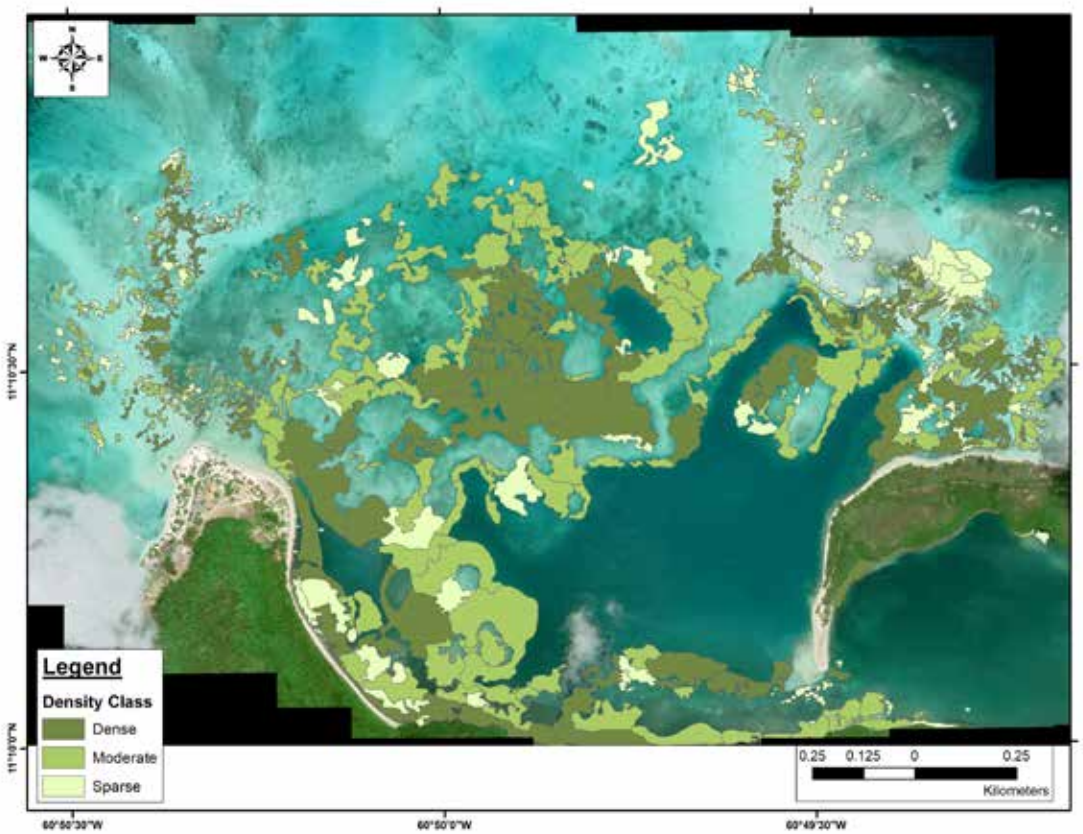


Figure 19 Finalised extent and density of Seagrass Beds in April 2022.

OBJECTIVE #2: To conduct an ecological assessment of seagrass beds in Bon Accord Lagoon

Ecological assessments were conducted within Bon Accord Lagoon, Kilgwyn Bay and La Guira Bay to assess the ecological health, seagrass productivity and physicochemical and water quality conditions. Originally, seagrass beds in Petit Trou were identified for assessment, however there was limited accessibility to the site. The parameters assessed were as follows:

1. **Water quality** - nitrates, nitrites, ammonia, phosphates, organic carbon and chlorophyll *a*
2. **Physiological parameters** - pH, salinity, temperature, dissolved oxygen
3. **Marine fauna** – An assessment of the resident marine fauna – vertebrate and invertebrate species through beam trawl surveys
4. **Seagrass distribution** – Assessment of benthic distribution of seagrass species and competitors to ascertain suitable donor sites through snorkel surveys
5. **Seagrass productivity** - Assessed by monitoring seagrass growth rates which serves as an estimate of seagrass health
6. **Seagrass biomass** – Assessed by monitoring the above ground and below ground biomass of leaves and roots respectively. It also serves as an indicator of seagrass health.

Please refer to the MARIN Tobago: Seagrass Scientific report for detailed method on the ecological assessments of seagrasses in south-west Tobago.

Outcomes of objective #2

Water Quality

Samples were collected in November 2022. The parameters tested were as follows: nitrates (NO3-N), nitrites (NO2-N), reactive phosphates (RPO4-P), ammonia (NH3-N), turbidity, total suspended solids (TSS), chlorophyll *a* and dissolved dispersed petroleum hydrocarbons (DDPH). None of the parameters tested exceeded USEPA limits for aquatic life. Only Station One in the Bon Accord Lagoon exceeded values for phosphates (0.04 mg/l) as outlined by Hemminga (1998), while the values for nitrates and nitrates stayed below the limits (Figure 20). The results show no indication of persistent water quality issues throughout the Bon Accord Lagoon and Kilgwyn Bay, which might hinder either the removal of seagrasses (at donor sites) or the replanting of seagrasses (at rehabilitation sites). See Marin Tobago, Seagrass Scientific Report for detailed results.

Benthic distribution of seagrass

The densest *Thalassia* beds were found at Site 3 within the Bon Accord Lagoon with an average of 209.7 shoots per quadrat (Figure 20). Site 8 within the Nylon Pool had the least dense beds with an average of 41.8 shoots per quadrat; this area is a recently colonised area. Other seagrass species, *Halodule wrightii*, were found in Stations 6 and 9 forming mixed seagrass beds with the *Thalassia testudinum*. The results indicated that Bon Accord Lagoon would be a good candidate for a donor site, given the high density of seagrass shoots that appeared healthy and not covered by encrusting organisms. Any damage from the removal of seagrasses would be quickly recovered and should not adversely affect the beds.

It was not possible to conduct snorkel surveys at Kilgwyn Bay and La Guira Bay because of poor visibility despite several attempts at different times of the year. This gives an indication of the high suspended sediment in the sites along the south coast compared to Bon Accord Lagoon.

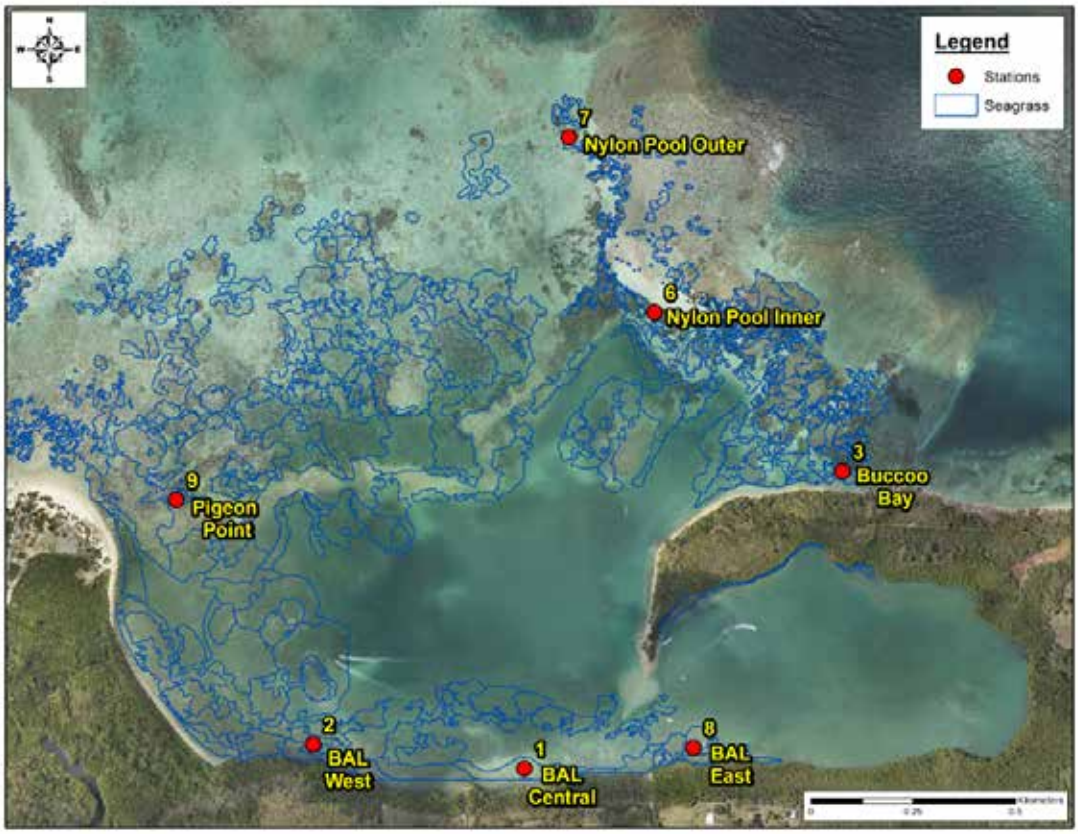


Figure 20 Sample Stations within the Bon Accord, Buccoo Bay, Nylon Pool and Pigeon Point area.

Marine fauna

A total of 121 individuals belonging to 28 species were observed at five sites in Bon Accord: Station 2, (BAL East), Station 3, (Buccoo Bay), Nylon Pool, Station 8 (BAL East) and at Station 9 (Pigeon Point). A total of 68 fish were observed belonging to 15 species. The most abundant fish species belonged to the mojarra family (Family: Gerreidae) and was found within the Bon Accord Lagoon. Puffer fish (Family: Tetraodontidae) was also common, as it was found at four sites. For fish species, the highest abundance (32), number of species (9) and diversity (1.77) were recorded at the Bon Accord Lagoon West (Figure 20). The lowest abundance (2), number of species (1) and diversity (0) were recorded at the Nylon Pool (Table 8).

Fifty-three invertebrates belonging to 13 species included gastropods, echinoderms, several crab species, sea cucumbers and squid were also observed. Pigeon Point recorded the highest number of species (6), number of individuals (30) and diversity (1.66) for invertebrates, while Nylon Pool recorded the lowest number of species (2), number of individuals (2) and diversity (0.69) (Table 8).

These results show thriving vertebrate and invertebrate communities within the Bon Accord Lagoon. The structural complexity created by the seagrass canopy provides refuge and breeding grounds for numerous invertebrates and fishes (Lewis & Stoner, 1983; Orth et al., 2006; Whanpetch et al, 2010; Thomson et al., 2016) leading to increased species abundance and diversity compared to areas without seagrass vegetation (Lewis & Stoner, 1983; Orth et al., 2006). This further highlights the necessity to protect thriving seagrass communities and rehabilitate historical sites as a means of conserving and enhancing biodiversity.

Beam trawl surveys at Kilgwyn Bay were not possible due to the shallow waters and rocky nature of the substrate.

Table 8 Number of species, number of individuals and Shannon-Weiner Diversity for fish and invertebrate species recorded at Pigeon Point, Bon Accord Lagoon (BAL) West, Bon Accord Lagoon (BAL) East and Nylon Pool for beam trawl surveys

	Pigeon Point	BAL West	BAL East	Sheerbird's Point	Nylon Pool
No. fish species	5	9	3	2	1
Total # of individuals (fish)	9	32	19	6	2
Shannon-Weiner Diversity Index	1.3	1.77	0.71	0.45	0
No. of invertebrate species	6	4	4	3	2
Total # of individuals	30	10	5	6	2
Shannon-Weiner Diversity Index	1.66	1.09	1.33	1.01	0.69

OBJECTIVE #3: To estimate the carbon stored in the seagrass beds of Bon Accord Lagoon

Nature-based solutions to climate change are now being broadened beyond terrestrial forests that protect natural sites rich in carbon storage. In particular, marine and coastal ecosystems, such as seagrasses, tidal marshes and mangroves, store large quantities of 'blue carbon' in both the plant biomass and the sediment below.

Blue carbon strategies build on the opportunity to mitigate greenhouse gas emissions and to enhance organic carbon sequestration through the conservation and/or restoration of marine and coastal ecosystems. The loss or deterioration of seagrass beds would not only lead to the loss of their carbon sink capacity but could potentially release the carbon already stored in their sediments. Natural carbon sequestration and storage is of importance in mitigating the imminent threats posed by climate change. Protection and restoration of seagrass meadows could be used as a climate change mitigation strategy because seagrass meadows can sequester a large amount of carbon for a very long term. Habitat protection could also prevent remineralisation of organic carbon buried in the sediment (Howard et al. 2014; Macreadie et al. 2015).

Compared to other types of vegetation, such as mangroves and terrestrial forests, there is still much to be learned about carbon sequestration in seagrass meadows, including the measurement of organic carbon content (OCC) in different types of seagrass meadows. The capacity to capture and store blue carbon in seagrasses of some regions is poorly studied, and such is the case of seagrasses in Bon Accord Lagoon Tobago. Studies on carbon storage in *Thalassia* dominated seagrass beds in particular are relatively scarce. This present study seeks to gain a first estimate of the carbon stored in the seagrass beds of Bon Accord Lagoon.

Sediment core samples were collected in July 2022 with assistance from the Department of Marine Resources and Fisheries, Tobago House of Assembly (THA). Duplicate cores were taken at 16 stations within the study site across the expanse of seagrass beds in areas with dense, moderate and sparse seagrass density. Sediment and seagrass biomass sample sections were analysed at the Marine Biological Laboratory, University of Boston.

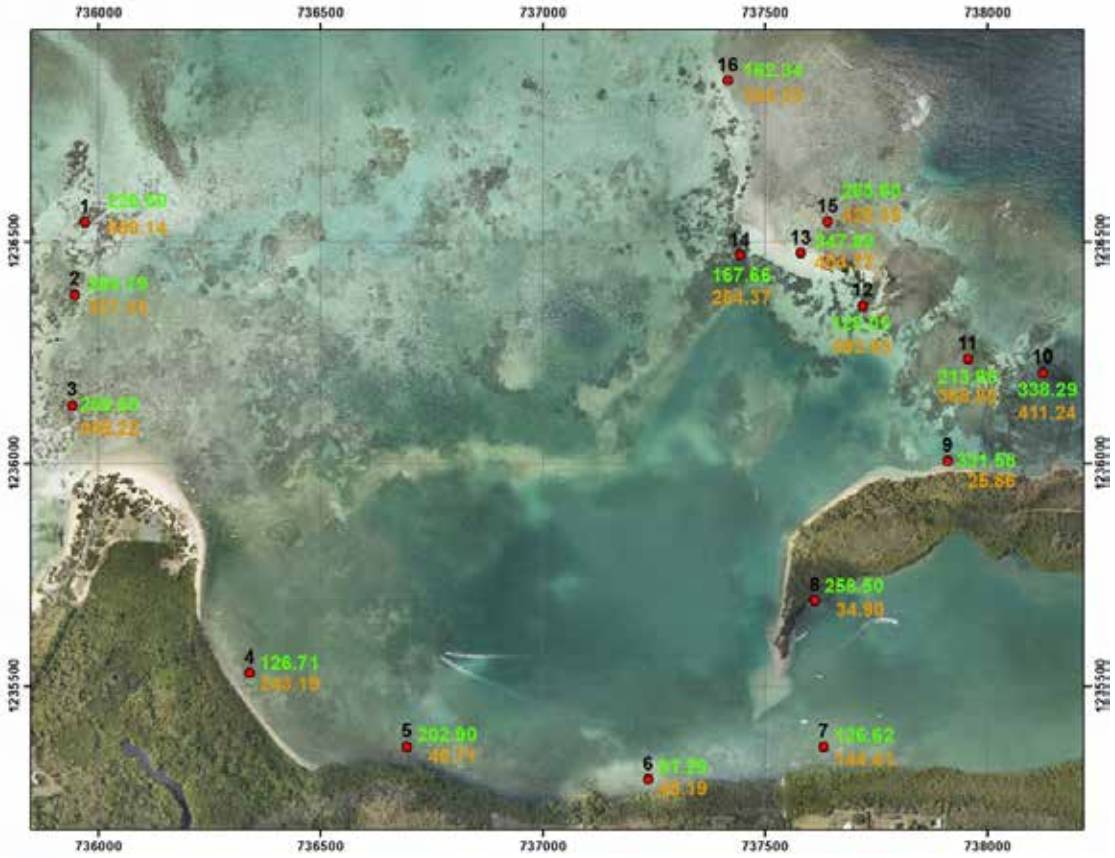
Outcomes of Objective #3

The stations were divided by region with Stations 1-3 encompassing the Pigeon Point area, Stations 4-8 encompassing the Bon Accord Lagoon area, Stations 9 – 11 encompassing the Buccoo Area and Stations 12 – 16 encompassing the Nylon Pool area (Figure 21). Results show that the storage of organic carbon is highly variable across the seagrass beds in Bon Accord Lagoon. The highest (organic and sediment) carbon storage was found in the vicinity of Pigeon Point (highest sediment carbon) and Buccoo (highest sediment and organic sediment), while the lowest carbon (organic and sediment) was surprisingly located within the Bon Accord Lagoon (Table 9). Further investigation in ongoing to interpolate the organic carbon storage based on density to other areas.

Table 9 Average values for organic and sediment carbon levels at different regions in south-west Tobago.

Region (Stn #)	Organic Carbon/ gm^{-2}	Sediment Carbon/gm^{-2}
Pigeon Point (1-3)	247.83 ± 16.67	2260.35 ± 482.47
Bon Accord Lagoon (4-8)	157.72 ± 62.59	517.85 ± 415.12
Buccoo (9-11)	291.84 ± 56.59	1368.28 ± 878.83
Nylon Pool (12-16)	196.08 ± 57.62	1998.21 ± 356.25

Areas around Buccoo and Pigeon Point are high use areas and also overlap with the seagrass distribution. Conservation considerations to protect the seagrasses and manage activities should be made for these areas. Given that the Bon Accord Lagoon is home to the largest seagrass community in the country and is within a MPA and RAMSAR Site, the results of the pilot highlight its blue carbon storage potential and provide another reason for its management and protection. The value of seagrass communities, in the midst of all the challenges they face, cannot be overstated. For this reason, the protection, and eventual expansion of seagrass communities at different sites in Tobago, not just the Bon Accord Lagoon, is a valuable asset.



The pilot study can provide the basis for a management plan for the protection of seagrass beds throughout the island and provide the basis for restoration.

Figure 21 Carbon stored (gm^2) for organic carbon (yellow) and sediment carbon (green).

OBJECTIVE #4: To trial different methodologies for suitability at the selected replanted sites

Two methods (both sediment-free) were trialled: BRC frames (Plate 10, left) (modification of TERFS™ (Transplanting Eelgrass Remotely with Frames System) and the metal pin method (Plate 10, right).

Plate 10 Seagrass shoots affixed to BRC frame (left) and U-pins (right) for replanting

Suitable seagrass samples that were in good condition (healthy, broad, complete green leaf, rhizomes, shoot length of at least two inches, no biofouling and attached rhizomes) were removed from within the Bon Accord Lagoon (Plate 10). About 400 seagrass shoots were collected using a dive knife to carefully separate from the bottom sediment. Seagrasses were rinsed of sediment and samples were kept in large containers with seawater to ensure they remained viable for the duration of the replanting exercises.

Plate 11 Collection of seagrass shoots for replanting. Photo credit Attish Kanhai

BRC Frame method: Two 6 m^2 BRC frames were used (total 12 m^2) for the seagrass replanting at the Bon Accord Lagoon site in April 2022 as a control site for the methodology (Plate 12). Two different seagrass densities were used with 216 shoots attached to the "higher density" frame and 150 shoots attached to the "lower density" frame. Shoots were tied carefully using twine ensuring the shoots were in a vertical and upright orientation. These frames were deployed at the site and anchored to the sediment using metal U pins. These same steps were repeated in June 2022 with the assistance of volunteers, at two different sites, one in Kilgwyn Bay and the other La Guira Bay.

Plate 12 Placement of seagrass attached to BRC frame. Photo credit Anjani Ganase

<u>Outcomes of Objective #4</u>

BRC Frame methods: Macroalgae became attached to parts of the metal frames where no shoots were tied and smothered the seagrass shoot making it difficult for the seagrass to root. Macroalgae is indicative of nutrient enrichment. While water quality monitoring showed no stations with excessive nutrient standards, higher resolution monitoring is needed in this area. The rapidly changing seafloor at the replanting site in Bon Accord Lagoon led to parts of the frames being

completely buried under the sand while other sections became uprooted. The sites at Kilgwyn and La Guira showed varying degrees of success for both methodologies. The frames became overgrown with macroalgae in sections where no seagrass shoots were attached. The algae began to smother seagrass shoots making it difficult for the seagrass shoots to root, similar to the control site. The high wave energy at Kilgwyn and La Guira uprooted some of the seagrass frames and deposited the frames on the shoreline. Others have not been recovered because of the poor visibility.

Metal pin method: 79 shoots were directly pinned to the seafloor at Bon Accord Lagoon using metal U pins. This was done by tying the rhizome carefully under the curve of the pin using twine. This was repeated at Kilgwyn Bay (Between Stations 5 and 10, Figure 22) and La Guira (Station 4, Figure 22) in June 2022. Eighty pinned seagrass units were outplanted at Kilgwyn which was difficult to do on rocky sediments.

Figure 22 Sites chosen for replanting in Kilgwyn Bay and La Guira Bay

The control site at Bon Accord Lagoon (Site 3) that was established in April 2022 showed some success with the U-pin as some shoots (approximately 30 – 40%) were able to take root and establish. Subsequent monitoring trips will determine the continued success of these shoots. The U-pin method proved to be more successful initially at both replanting sites in Kilgwyn as some managed to take root and grow. An estimated 40% of the U-pinned shoots have survived to date. However, rough seas, and turbid waters limited the monitoring capability at the sites and a definitive assessment of replanted shoots was not possible.

Given the challenges stated above, subsequent trips will be conducted when sea conditions are calmer to allow proper assessments. It seems clear, however, that one methodology, namely using the U-pins, has a greater chance for success for replanting. Full details of the trials are included in the MARIN Tobago, Seagrass Scientific Report.

Lessons learned from seagrass replanting trials

1. The frames became overgrown with macroalgae that began to smother seagrass shoots making it difficult for the seagrass shoots to root as at the control site. Fouling of artificial surfaces by macroalgae may be an issue in nutrient-enriched environments. For this reason water quality assessment at regular intervals during the wet and dry seasons is needed to properly assess the replanting sites.
2. The high wave energy at Kilgwyn Bay uprooted and deposited some of the seagrass frames on the shoreline. The U-pin method proved to be more successful initially at both replanting sites in Kilgwyn as some managed to take root and grow.
3. Further investigation of the oceanographic conditions of Kilgwyn Bay is needed. Wave and current models will be done to aid in the replanting site selection process.
4. The attachment of artificial support (e.g. frames and U-pin) to the rocky seabed is a challenge and alternative methods need to be explored.

OBJECTIVE #5: To build community engagement during the seagrass replanting process

IMA hosted two in-person workshops in south-west Tobago at the Buccoo Multipurpose Facility in April 2022. Key stakeholders included representatives from governmental, non- governmental organizations, community-based organisations, fishers, divers and other resource users. These stakeholders were also invited to participate in upcoming restoration activities. The objective was to educate stakeholders and resource users about the value of seagrass meadows, bring awareness to the ecosystem services they provide, as well as the types of seagrass restoration methodologies to be tested at selected restoration sites in Tobago. The workshops provided an opportunity to get volunteers to sign up for replanting activities which were scheduled for June 2022.

Outcomes of objective #5

A total of 26 persons attended the stakeholder workshops representing a variety of organizations including the Department of Marine Resources and Fisheries (DMRF), Save our Sea turtles (SOS), Frontier Divers, Speyside Eco Marine Park Rangers (SEMPR), Buccoo Reef Trust (BRT), Tobago Tourism Company, All Tobago Fisherfolk Association (ATFA) as well as individuals with a personal interest in the topic. In June 2022 replanting of seagrasses took place at two sites along Kilgwyn Bay with 10 volunteers. An area of 24 m^2 was replanted in half a day. Based on this, a minimum area of 96 m^2 will take the same number of volunteers four days when considering that replanting can only take place for half day at a time.

The enthusiasm from DMRF, SEMPR and Tobago Tourism Company, in particular, was noteworthy, during the workshops and replanting exercises. They were interested in the methodologies being deployed and in particular, patrol officers from DMRF were interested in ways their roles could be used to protect and enhance the seagrass communities of Tobago. Volunteers from these organisations participated in the replanting efforts (Plate 13). Even though these activities took longer than anticipated, members of these organisations stayed until it was completed. They also indicated interest in participating in further replanting activities in the future.

One major outcome of these workshops is the need to further educate the general public about the importance of seagrasses, especially those involved in the tourism sector as knowledge of their value is lacking. It was indicated by workshop participants that new information of the value of seagrasses should be shared further.

Plate 13 Volunteers attending the workshops and assisting in replanting of seagrass shoots

Ongoing research to inform on management and restoration of seagrass

1. Investigate further into site selection for Kilgwyn Bay and other sites around Tobago using nearshore hydrodynamics, water clarity and water quality.
2. Trial and select sites appropriate for replanting techniques based on best practices in literature
3. Strengthen the volunteer network including creation of a volunteer stakeholder list for future seagrass replanting exercises
4. Assess the maximum capacity of the donor sites within Bon Accord Lagoon.
5. Expand outreach activities in seagrass specific awareness and management practicesto assist in seagrass replanting and management.

Applying seagrass restoration to Tobago

GOAL: To investigate and implement the **best strategies** for the vegetative propagation of *Thalassia testudinum* so as **to increase** seagrass coverage **and improve** ecosystem function

1. **Objective setting**
    - Investigate different methodologies to propagate vegetation growth of *Thalassia testudinum*.
    - *Thalassia testudinum* was the chosen species for restoration
        - o This species has the highest biomass and productivity of the three seagrass species found in south-west Tobago and is the climax species in the Caribbean.
        - o Historical data exists for this species including productivity, biomass and shoot density data.
        - o Fauna surveys conducted indicate that this species support high faunal biodiversity

- Although the reproductive strategy and timing of *Thalassia testudinum* in the area remains unknown, successful vegetative growth and high coverage of seagrass in Bon Accord Lagoon suggests this species will be successful in vegetative propagation.

2. **Transplant site selection**

   - Further investigations will be conducted to determine areas within Kilgwyn Bay that may be suitable for replanting, as well as alternative sites in Petit Trou and north-east Tobago - Lucy Vale, Speyside and King's Bay
   - There is potential for testing of other restoration methodologies at Kilgwyn.

3. **Transplant unit and technique**

   - Shoots for vegetative growth will be used until more insight is gained into the reproductive biology of *Thalassia testudinum*
   - Restoration by seeds will allow for a larger scale of restoration and should be investigated.

4. **Habitat enhancement**

   - BRC was used for stabilization of the restoration activity. Although this was unsuccessful at the site chosen at Kilgwyn it is still possible that:
     - It may be used at other sheltered sites
     - Use of weights (e.g. bricks) to further anchor the stabilization technique may improve the effectiveness of the strategy.
     - Use of PVC coated wire frames is preferred and will allow for re-use as opposed to frames vulnerable to corrosion

5. **Selection of appropriate donor site**

   - Donor sites present in Bon Accord - east of Buccoo (north of Sheerbird's Point) and near Pigeon Point
   - Selection from the edges of areas mapped for sparse to moderate seagrass densities.

6. **Spreading of risks**

   - Transplanting from multiple donor sites to multiple replanting sites to minimise any kind of damage to donor beds and to spread the risks over different replanting sites.
   - Regulating the number of times and the amount of seagrass being removed from the donor area to facilitate natural regrowth
   - Allow for replanting at different times of year to account for changing conditions throughout the year to increase chances of success

7. **Assessing hydrodynamics: optimising techniques and accounting for ecosystem engineering effects**

   - Use hydrodynamic modelling to determine most suitable sites for replanting.
   - Consider seasonal and temporal changes to hydrodynamic conditions to ascertain conditions most suitable for replanting.

8. Review of objectives

- Reassess objectives after meeting with stakeholders and taking into consideration new information.

9. Timing of restoration activities

- Timing of restoration is critical to ensure best survival of transplants particularly after stress of handling. The ideal time for restoration activities is during the dry season, avoiding the windier months. Therefore, April to June in Tobago is preferred.
- According to Juman (2005), monitoring of *Thalassia testudinum* showed that productivity in dry season was higher in March and June with September having the lowest value. This suggests that March and June would be better months to conduct restoration activities as faster growth rates will be beneficial for new transplants.

10. Fostering community engagement

- All relevant stakeholders in Tobago were invited to the seagrass restoration workshops and activities. They will continue to be informed of progress of the project. These workshops should not coincide with activities, such as the Tobago Heritage Festival or Tobago Carnival, in order to encourage maximum participation of the public.

Upscaling and restoration costs

Seagrass replanting is labour intensive and requires covering an extensive area for the greatest chance of success. This section provides a basic understanding of the cost of implementing different restoration strategies in Tobago. The restoration cost is measured for a single replanting methodology. The activity starts with the procurement of equipment, collection of seagrass shoots and ends with planting of shoots. Monitoring and evaluation costs are separate from the restoration costs. Expenses are divided into three main cost categories: equipment, personnel and logistics. The equipment cost focuses only on the materials needed for construction, outplanting and monitoring (Table 10). Personnel cost refers to the salaries of a minimum of three staff members - two experts in marine science and one technician. Logistical costs include travel to Tobago, accommodation and boat rental. All methods include long-term monitoring which can be conducted by the same expert team or trained personnel or partner entities. Likely variations in any of three cost categories may result from changes in personnel numbers and level of expertise, the use of alternative materials, and the compilation of activities (Table 10). For each site, it is recommended that several activities including hydrodynamic modelling, site mapping and ecological surveys take place prior to replanting (Table 10). This will ensure site suitability for restoration to ensure the correct replanting methods are employed.

Anchoring of shoots with pins

Cost

The costs consider the option of anchoring seagrass shoots to the seabed using U-pins. For successful replanting, 1100 to 1700 shoots will need to be replanted over an area of 96 m^2. The total cost of four days of anchoring U-pins to the seabed is ~24,000 TTD (Table 10). A list of the basic equipment for seagrass replanting is provided in Table 11.

Timeline

The initial activities consist of the procurement of steel to be cut and shaped into pins. This should take no more than three days. The collection of shoots, tying them to the pins with biodegradable twine and fixing them to the appropriate site should take no more than four days. The collection of shoots should occur in early mornings, while the tying of shoots to the frames could occur from midmorning to midday. This is very labour intensive and will require a number of volunteers. Monitoring of the replanting site will entail snorkel surveys and counts for those that have survived. Rough sea conditions and low visibility can sometimes hinder the monitoring activities, so appropriate times of year and sea conditions are necessary for these activities. Subsequent to replanting, every four months, or at least once every quarter, the replanted sites should be monitored (Figure 23).

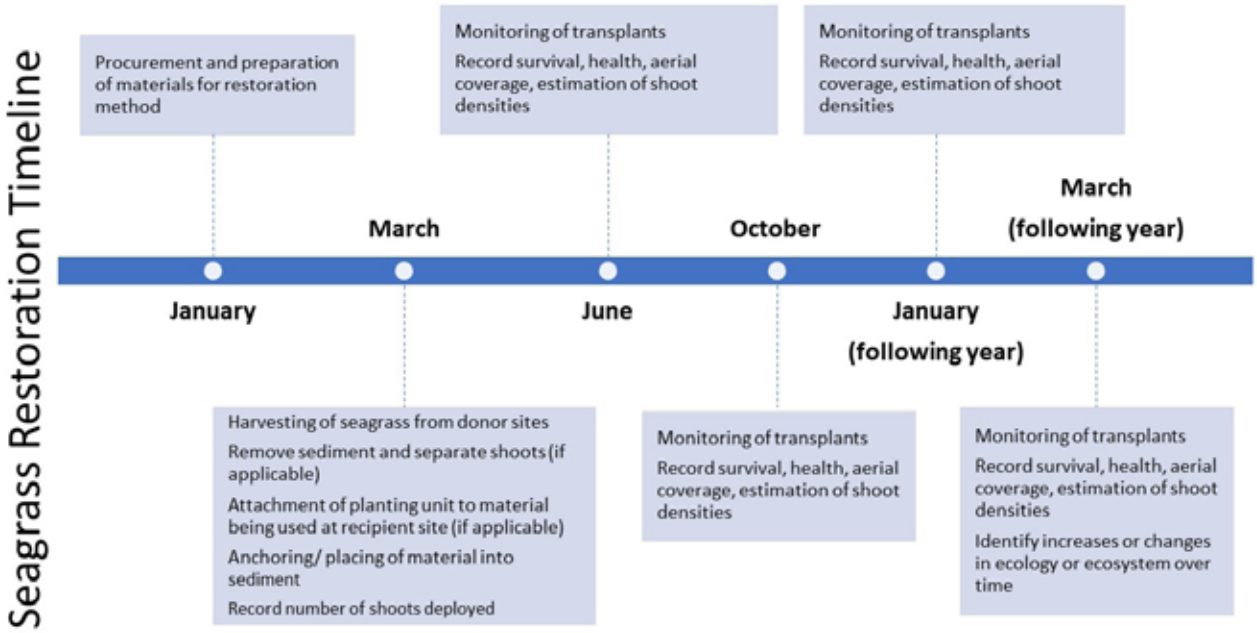


Figure 23 Timeline for the use of anchoring methods in seagrass restoration

Frame or Hessian Bag Method

Cost

The costs consider the option of anchoring seagrass shoots to the sea bed using BRC frames or Hessian bags. The total cost of four days of anchoring BRC frames in an area of 96 m^2 to the sea bed is ~37,500 TTD (Table 10). A list of the basic equipment for seagrass replanting can be found in Table 11.

Timeline

The initial activities consist of the procurement of BRC frames and cutting into 1 x 1m sections that are manageable to be transported to the replanting sites. This should take no more than three days. The collection of shoots, approximately 1100 to 1700, tying them to the frame with biodegradable twine and fixing them to the appropriate site should take no more than four days. The collection of shoots should occur in early mornings, while the tying of shoots to the frames should occur from midmorning to midday. This is very labour intensive and will require a number of volunteers for successful completion. Monitoring of the replanting site will be similar to those outlined in Figure 23.

Coring method, sod and plugs

Cost

The costs consider the option of coring sections of seagrasses from a healthy donor site and replanting to the rehabilitation site. The total cost of four days of coring seagrasses is ~36,500 TTD (Table 10). A list of the basic equipment for seagrass replanting can be found in Table 11.

Timeline

The initial activities consist of creating PVC corers to be used for coring sections of seagrasses. This should take no more than three days. At the replanted sites, the same cores would remove benthic sediment and the seagrass cores would fill or plug the area. The collection of plugs should occur in early mornings while the replacement of cores to the rehabilitated site should occur from midmorning to midday. This should take no more than four days. This is very labour intensive and will require a number of volunteers for successful completion. Monitoring of the replanting site will be the same as those described in Figure 23.

Table 10. Outline of budget for seagrass activities

Activity (one site, one replanting method)	**Duration of activity/ days**	**Equipment Cost**	**Personnel Cost**	**Logistics Cost**	**Total Cost (TTD)**
Site mapping	7		12000	10000	22000
Ecological surveys	5		3000	10000	13000
Hydrodynamic modelling	5	600000	3000	10000	613000
Anchoring shoots with pins					
Procurement and Construction of pins	3	5,500	8,000		13,500
Installation of pins at selected site	4		12,000	12,000	24,000
Frame or Hessian bag method					
Construction of frames	3	5,500	8,000		13,500
anchoring of frames and shoots	4		12,000	12,000	24,000
Coring method (sod and plugs)					
Construction of cores	3	4,500	8,000		12,500
Coring and replanting	4		12,000	12,000	24,000
Monitoring Costs					
Monitoring of planted sites	2 days every 3 months for first year		20,000	40,000	60,000
Long term monitoring of planted sites	2 days twice a year		10,000	20,000	30,000
Other monitoring equipment					
SCUBA gear and snorkelling equipment					45,000

Notes: This budget focuses on groups of activities for different stages of the seagrass restoration plan. This outline can then be used to plan the schedule accordingly for each site whether southwest or northeast Tobago.

Table 11 Minimum equipment checklist for different strategies in seagrass restoration

	Restoration Strategy			
Item	BRC Frame	Hessian Bags	Metal U- pins	Cores (Sod and Plugs)
Metal frame	x			
Metal U pins	x		x	
Corers				x
Hessian bags		x		
Biodegradable twine	x	x	x	
Dive knife	x	x	x	x
Shovels	x	x	x	x
Scissors	x	x	x	
Tags	x	x	x	
Plastic baskets	x	x	x	
Plastic tub/cooler				x
Wire cutters	x	x	x	
Blocks for anchors	x	x		
Gloves	x	x	x	x

Restoration and sustainability

Essentially there about six foundational features that would drive effective marine management and restoration strategies:

1. **Governance/ stewardship -** The top-down government approach through the formation and implementation of legislation, policies, and plans related to marine protection and management. This can be complemented by the bottom-up approach of environmental stewardship, community interest and scientific backing. Key policies to consider:

- Marine areas (preservation and enhancement) Act (1970) - https://agla.gov.tt/downloads/laws/37.02.pdf
- National Protected Areas Policy 2011 - http://www.biodiversity.gov.tt/images/stories/pdf/final_protected_areas_policy_2011.pdf
- National Protected Areas System Plan (2019) - https://drive.google.com/file/d/19f3h2N3pFjAJVxzIg4ccrMDZr5E8b0XH/view
- Draft Integrated Coastal Zone Management, Policy Framework (2019) - http://www.iczm.gov.tt/wp-content/uploads/2019/04/Draft-Integrated-Coastal-Zone-Management-Policy-Framework-Amended-April-2019.pdf
- Vision 2030, National Development Strategy of Trinidad and Tobago - 2016 - 2030 - https://www.planning.gov.tt/sites/default/files/Vision%202030-%20The%20National%20Development%20Strategy%20of%20Trinidad%20and%20Tobago%202016-2030.pdf

"Ecosystem restoration is enabled by policies and measures that promote its long-term progress, fostering replication and scaling up" - UN Principle # 10 for ecosystem restoration

2. **Political will/ community will** – Both are essential for driving actionable change, especially for management challenges that require cross-sector prioritisation.

3. Research and technological capacity – Trained personnel must have tools, equipment and methodologies to conduct restoration and enable effective management.

4. Sustainable finance – Restoration is labour intensive and expensive. Medium to long-term (5 to 10 years) private-public funding partnerships have been successful with other conservation projects.

5. Awareness – Awareness of all components (risks, benefits etc.) of the ecosystem by all stakeholders – including decision-makers, the managers, and the resource users.

6. Broad engagement and inclusion – Stakeholder engagement must occur at all steps in the process from design, planning, implementing and even in scenarios of adaptations. This is to encourage understanding, and even participation in problem-solving during consultative activities. This co-management approach is key for project acceptance, building awareness and even dividing responsibilities and resources among government, communities, NGOs and research (GEF LME: LEARN. 2018).

> *"Ecosystem restoration must be inclusive and participatory and must consider social fairness and equity throughout the process."* - UN Restoration Principle #2

Marine Resilience Network (MRN)

Marine Resilience Network refers to the major stakeholders that will assist in carrying out the steps of the resilience-based management pathway. The Network would primarily be a partnership of experts, government, academia, NGOs, resource users and private entities committed to assisting in the marine resilience plan for the monitoring, management and restoration of Tobago's marine ecosystems. Additionally, the Marine Resilience Network would be informed and supported by a regional and international cohort of researchers and managers who work in marine management and restoration for climate change resilience. The MRN will benefit from information sharing and lessons learned in strategising and implementing ecosystem restoration and management initiatives. For example, an established partnership with SECORE International, an NGO focused on sexual strategies for coral restoration, was key to this pilot study and will be essential moving forward.

The first task of the Marine Resilience Network will be to draft a resilience strategy that is informed by several local and scientific knowledge inputs including any that relate to current conditions, ecological functions, future predictions, management status, and key challenges. It is essential that there is sufficient understanding of the current state of the marine ecosystem. The resilience strategy will also be guided by an agreed resilience vision and priority actions will be decided upon by the MRN. The next step will be the implementation of the resilience-based management informed by outlined priorities and with assigned roles for stakeholders for various tasks in the process.

Table 11 Draft Management pathway with activities and designated roles

Management Pathway	Activity	Potential Stakeholders
Maintenance pathway	Management of chronic and local issues Enforcement of rules Awareness and education of marine ecosystems	Management entity Educators Conservation clubs NGOs
Disturbance/ ecosystem change - alert communications	Disturbance alerts - coral bleaching/ storm events Reporting to governing body and research institutions	Research institution Reef users - business, NGOs, community members
Monitoring for change	Surveys	Research institution/ citizen science/ NGOs
Management of threat	Reduce other chronic stressors temporarily with signage and building awareness	Management entity, NGOs
Management for recovery	Assessment for ecological state and potential for recovery	Research institutes, management entities
Restoration	Gathering of stocks, outplanting	Students, NGOs, guided by research institutions and management entities
Restoration recovery (survivorship	Monitoring surveys	Research institute, NGO, students etc.

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Notes

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