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Strategies for Large Scale Coral Reef Restoration for Coastal Resilience in the Seychelles

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Document Control Sheet

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Synopsis:	**This progress report is the final report for Selection# 1258225: Strategies for Large Scale Coral Reef Restoration for Coastal Resilience in the Seychelles.**	

Executive Summary

Background

The World Bank with financial support from the Global Facility for Disaster Reduction and Recovery (GFDRR) is providing technical assistance to the Government of Seychelles to enhance coastal management and upscale the implementation of coral reef restoration for coastal protection. Coral reefs in the Seychelles have been impacted by several coral bleaching events over several years, and to a lesser extent by runoff of nutrients and sediment, and impact of human activities on or around reefs.

The loss or degradation of these important systems has impacted the ecosystem services they provide, such as:

- Reduced potential to dampen wave energy and the resultant increase in beach erosion and wave related flooding.
- Reduced habitat for fish and other economically important species.
- Reduced access and amenity for tourists.

In recognition of the impacts of the loss of coral reefs, and the important role that coral restoration can play in improving a range of ecosystem services, the World Bank and the GFDRR have funded this project to develop a strategic approach to coral restoration in the Seychelles. In addition to identifying optimal locations for restoration, the project also entails determining the costs involved with coral restoration at the scales required to achieve desired outcomes; identification of potential financing and funding sources; and identifying an appropriate governance model for managing reef restoration funding and activities.

Approach

Environmental Approach

Environmental aspects of the project included desktop assessments, field validation studies in two locations and significant engagement with key stakeholders. The project is closely associated with the Coastal Zone Management Plan for the Seychelles which has been developed by the World Bank.

Several criteria were used to identify and prioritise locations for coral reef restoration. Highest priority was assigned to those locations where coral restoration alone had a high potential of achieving outcomes. However, we recognised that there are a number of other locations where coral restoration has potential for success and where restoration can support coastal management objectives if restoration was combined with engineering solutions. These medium priority locations were also included in the overall business case and assessment of their importance to the Seychelles coastal communities and economy.

A series of principles were identified to support to long-term viability of coral reef restoration. These are:

- Restoration sites should be actively managed, including removing algal growth, preventing human use of and access to target locations.
- Where possible select sites where there is potential for larval supply to augment coral restoration activities.
- A range of coral restoration activities should be used to help achieve scale at each location. Some structural input may be required to reduce erosion and to provide additional substrate for coral gardening.

- The influence of climate change should be considered. What is the time period over which coral restoration will deliver outcomes? Will this deliver desired outcomes for sufficient time to ensure it is worth the risk of loss in a climate affected future?
- Sites with a diversity of habitat types should be prioritised.
- External impacts such as nutrient or sediment runoff should be reduced and monitored.
- The potential for short, medium, and long-term outcomes from the restoration activities should be considered.
- Locations at which multiple benefits can be derived from restoration should be prioritised.
- More information about each location should be collected to design the approach, management plan and monitoring activities before restoration is undertaken.
- Build on existing successes.

Business Case Development

An economic framework for evaluating coral reef restoration projects in Seychelles was developed, using a cost benefit analysis (CBA) approach. The economic framework was used to inform an evaluation of options for coral reef restoration at two locations (La Passe and Au Cap). Although data was too limited to complete a full CBA at these sites, the economic evaluation helped to identify the preferred restoration options and most significant benefits and beneficiaries.

The outcomes of the detailed case study at these two sites were used to underpin the development of a business case for coral restoration across the Seychelles. The business case was developed in consideration of other similar and innovative approaches globally and was informed through initial stakeholder engagement to ensure it was applicable specifically for Seychelles. The business case examined potential sources of revenue, governance arrangements, monitoring and evaluation, and delivery strategies, risks and barriers. The business case also identified a range of recommendations for future work that would be beneficial for the refinement and finalisation of a business case for national coral reef restoration program in Seychelles, including stakeholder engagement to test and refine the proposed approach.

Environmental Findings

There is limited data about reef and general marine ecology at some locations, which reduces the ability to assess restoration potential and priority. Most locations can potentially benefit from reef restoration. Generally, however, this will not achieve desired objectives unless implemented in tandem with engineered solutions to reduce wave energy and provide substrate for coral.

Climate change creates a major risk for coral reefs and for coral restoration activities, which could impact all elements of restoration including, for example, coral nurseries and planting. Land-based coral nurseries are better suited to being able to withstand bleaching events and can ensure that coral restoration can restart rapidly if bleaching events occur and impact restored areas.

Regulation and enforcement are also critical for supporting successful restoration, particularly to reduce anthropogenic impacts on nearshore reefs.

Location	Preliminary prioritisation
MAHE	
Anse aux Pins	Medium priority or additional management required
Au Cap	Medium priority or additional management required
Anse Royale	Medium priority or additional management required
Baie Lazare	Medium priority or additional management required
Anse La Mouche	Medium priority or additional management required
Anse Boileau	High priority
Presidents Village	Not recommended or insufficient data
Baie Ternay	High priority
Beau Vallon	High priority
North East Point	Not recommended or insufficient data
LA DIGUE, PRASLIN AND OTHERS	
La Passe	Medium priority or additional management required
Anse Severe	Not recommended or insufficient data
Anse Consolation	Medium priority or additional management required
Grand Anse	Medium priority or additional management required
Anse Kerlan	Not recommended or insufficient data
Anse Boudin	Medium priority or additional management required
Cote D' Or	Not recommended or insufficient data
Petite Soeur	High priority
Grande Soeur	High priority
Cosine/Cousin	Not recommended or insufficient data

Case Study Locations La Passe and Au Cap

Two locations were selected for field investigations and application of a cost benefit analysis framework. These were La Passe and Au Cap. The results of the field surveys highlighted the very low cover of coral at the two sites. The table below shows the types of substrate at each location and the percent cover by coral, seagrass and various alga taxa.

Benthic Category	Au Cap	(La Passe)
Live hard coral cover (LHCC)	3.6	1.5
Standing dead coral	0.5	0
Rock	19.8	59.5
Rubble	67.5	57.3
Sand	13.5	32.4

Benthic Category	Au Cap	(La Passe)
Macroalgae	45.5	11
Turf	8	34
Crustose coralline algae (CCA)	1.5	1
Seagrass	0	47
Total number of urchins	379	201
Herbivorous fish	65	8

Economic Assessment Findings

Economic Assessment of La Passe (on La Digue)

La Passe (on La Digue) is the primary area of economic activity on the island. It includes a range of environmental, social and economic assets (hotels, private residences, hospitals, roads, marinas, cafes, agricultural lands and restaurants, beaches, seagrasses and mangroves).

A range of potential reef restoration options are possible, but restoration should be limited to the reef shoulder and not the reef flat to ensure optimal results. It is essential that complementary management actions are implemented to enable desires objectives to be achieved. There are a variety of benefits that can be derived from coral restoration at this location. These include tourism, small business, community, avoided costs of large-scale infrastructure development and maintenance (e.g. seawalls), ecosystem services provided through restoration. Three options were considered at each location These were:

Option 1. Artificial reef sited to reduce wave runup. Involves developing and deploying new artificial structures to provide protection from flooding and erosion.

Option 2. Artificial reef with coral gardening sited to support coral growth – involves developing and deploying new artificial structures with additional provision of live coral on new substrate.

Option 3. Coral gardening. Transplantation and microfragmentation – involves the provision of live coral on existing substrate.

Benefit type	Weighting	Option 1	Option 2	Option 3
Benefits				
Tourism benefits including benefits for businesses	40%	2	4	3
Community benefits including coastal resilience	20%	2	4	3
Local business benefits (non-tourism related)	5%	1	4	4
Other ecosystem service benefits	5%	4	3	2
Avoided infrastructure costs	30%	4	3	2
FINAL SCORE (weighted total)		**2.65**	**3.65**	**2.7**
Costs				
Upfront expenditure		High	Medium	Medium
Ongoing maintenance		Low	High	High

Benefit type	Weighting	Option 1	Option 2	Option 3
Opportunity costs		Low	Medium	High
Risks				
		Low	Medium	High

Economic Assessment of Au Cap

The profile of the reef at Au Cap is similar to that found at La Passe. The reef condition is considered to be poor, with very low live coral cover compared to other species and large areas of rubble and bare rock.

The same three option as the la Passes case study were compared.

Benefit type	Weighting	Option 1	Option 2	Option 3
Benefits				
Tourism benefits including benefits for businesses	10%	2	3	2
Community benefits including coastal resilience	30%	3	2	1
Local business benefits (non-tourism related)	20%	1	3	3
Other ecosystem service benefits	10%	3	2	2
Avoided infrastructure costs	30%	4	3	2
FINAL SCORE (weighted total)		**2.7**	**2.5**	**1.8**
Costs				
Upfront expenditure		High	Medium	Medium
Ongoing maintenance		Low	Medium	High
Opportunity costs		Low	Medium	High
Risks				
		Low	Medium	High

Financing Coral Restoration in the Seychelles

A business case was developed for the 15 locations identified as having potential for coral reef restoration (including Au Cap and La Passe). The business case included an assessment of the benefits and costs of restoration, governance arrangements and financing mechanisms. Based on the ecological conditions, benefits and cost at each site, an appropriate restoration technique was selected. The key benefit identified at the majority of sites was flood reduction and protection from coastal erosion. Other key benefits from coral restoration were considered for each site included tourism, community benefits, fisheries and carbon sequestration.

The estimated cost of a coral reef restoration strategy across these 15 sites is ~ $18.4 to $26.7 million, with an additional total maintenance cost of ~$1.3 to $1.8 million with an implementation timeline estimated at six years. This would require significant investment in upscaling coral nurseries across Seychelles, in order to achieve such large scale coral restoration. The assessment of potential revenue streams has identified that the program could mobilise revenues of approximately $7.3 million per year. However, the majority of the revenue ($6.6 million per year) is dependent upon the use of a green taxes and levies, at least part of which (e.g. a new Existence Levy) may be unpalatable to stakeholders and Seychelles Government. Only $0.7 million per year is available from other sources, excluding revenues sources that have relatively low certainty and high risk.

Implementation of a large scale coral reef restoration strategy requires an innovative governance structure and financing model. Implementation should therefore be overseen and monitored by an independent, highly respected and trusted body, which will enable to adapt the strategy accordingly. To be successful, a national strategy will require participation of all the stakeholders. Success will depend on the involvement of a range of organizations including NGOs, scientists, businesses and industry, and the government. This study concludes that it is possible to build on existing institutions, such as the Seychelles Conservation and Adaptation Trust (SeyCCAT).

Implementation of a National Coral Restoration Plan for the Seychelles

The full implementation of a large expensive initiative such as this will take time. Funding is challenging and it is important that this project can be integrated into a variety of others to ensure implementation. Prioritised areas may differ as a result. For example, the Coastal Zone Management Plan for the Seychelles identifies areas where coral restoration is an important management tool. This may result in funding becoming available for implementation which can be guided by the principles of this plan and the proposed governance structures.

Effective delivery of a large-scale coral restoration program requires a number of key activities. The scale of coral restoration requires involvement of a number of organisations, each playing critical roles in ensuring effective operation and governance.

Short-term successes and outcomes can be monitored and reported and may ultimately lead to further investment.

Key activity	Risks or constraints to manage	Examples of implementing organisation(s)
Establish and manage coral reef nursery	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and commercial businesses
Site-specific project design, including use of artificial reef	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and commercial businesses
Implementation of coral reef rehabilitation, e.g. coral gardening and transplantation	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and commercial businesses
Monitoring of rehabilitated coral reef	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and commercial businesses
Governance and administration	Ineffective governance and a lack of administrative capacity and capability can prevent the program from being implemented, including attraction of finance, due to the higher risk of program-failure	Independent and centralised group with well-developed and functional governance structures and excellent stakeholder relationships (including trust), from all potential stakeholder (project practitioners, project financiers or funders and government).

Key activity	Risks or constraints to manage	Examples of implementing organisation(s)
Marketing, communication and stakeholder engagement	Ineffective communication may result in disengagement or loss of confidence in the project. This may lead to a loss of support for the program and a loss of parties with sufficient capacity to implement	Independent and centralised group with well-developed and functional governance structures and excellent stakeholder relationships (including trust), from all potential stakeholder (project practitioners, project financiers or funders and government). Will manage centralised functions such as marketing and engagement.
Monitoring, evaluation and reporting (MER)	Ineffective and non-independent MER may prevent objectives from being achieving due to a lack of adaptive management of risks	Independent and centralised group with well-developed and functional governance structures and excellent stakeholder relationships (including trust), from all potential stakeholder (project practitioners, project financiers or funders and government) Will manage centralised functions such as monitoring and evaluation and reporting.

Key Findings

- Coral reefs in the Seychelles have been decimated through bleaching events and a variety of other pressures.
- This has severely impacted the ecosystem services that are provided by coral, including wave energy mitigation (increasing the erosion and flooding on the coastline), tourism and fishing.
- An assessment of the Seychelles has identified and prioritised a number of locations where coral restoration can be undertaken to provide ecosystem services which have been disrupted.
- In most locations coral restoration will need to be done in conjunction with engineered options to ensure outcomes can be achieved at scales that address the issue.
- A case study at La Passe was undertaken to explore the challenges and opportunities in more detail.
- Options for financing coral reef restoration at a Seychelles wide scale have been identified and a business case for restoration has been developed.
- The business case had addressed many of the requirements that are needed to attract finance. This includes governance, restoration approach (including placement).
- It is important that adaptive management if implemented around coral restoration activities as climate change is likely to impact coral restoration activities.
- Successful delivery depends on the involvement of a range of organisations including NGOs, the research sector, business and industry and government.
- It is critical that the operation is overseen by an independent, highly respected and trusted body.
- This is a long-term project which can build on other initiatives such as the implementation of the Coastal Zone Management Plan. These can help to identify funders and partners to support implementation.

Recommendations

- A pilot-feasibility study should be undertaken to underpin the implementation of the large-scale program. This would help to:
  - Refine stakeholder engagement required to achieve social licence to operate.
  - Test the potential for achieving integrated finance approaches.
  - Undertake detailed assessment of restoration/hybrid engineering approaches that accord with the values of stakeholders, and which are necessary to achieve desired coastal zone management outcomes in the test location.
- Following successful outcomes from the pilot study, a targeted large-scale coral restoration program should be implemented to fund and manage coral reef restoration activities which can help to deliver coastal zone management objectives in the Seychelles.
- This restoration program should be overseen by an independent body which is responsible for obtaining and allocating funding, driving engagement and implementation and monitoring and reporting on the achievement of outcomes.

- The program should align with policy and program development such as the Coral Reef Policy that is currently under development.
- Alignment with other legislation, policy and management can help to ensure that government organisations which are responsible for addressing other pressures which impact resilience of coral reefs such as catchment runoff (sediment and nutrients), fishing pressure, and tourism related pressures, prioritise and implement actions that are consistent with the reef restoration objectives and activities.
- A component of available funding should be committed to obtaining and developing new knowledge about leading practice in coral restoration to ensure the program remains cutting edge and adopts the most effective methods that can help to obtain long-term outcomes.
- The program should not replace, but should align with and support information exchange with other non-government programs that are focussed on achieving biodiversity outcomes.

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1 Introduction

1.1 Project Background

The World Bank - with funding from the Resilience to Climate Change program of the Global Facility for Disaster Reduction and Recovery (GFDRR) - is providing technical assistance to the Government of Seychelles to enhance coastal management and upscale the implementation of coral reef restoration for coastal protection. The overarching objective of this assignment (Selection# 1258225 – 'Strategies for Large Scale Coral Reef Restoration for Coastal Resilience in the Seychelles') is to support the World Bank / GFDRR and the Government of Seychelles to develop a strategy for the implementation and financing of large-scale coral reef restoration to improve coastal resilience in the Seychelles.

This study had three key objectives which were addressed as staged tasks throughout its execution. These were:

(1) Identify causes of degradation and evolution of coral reefs, including climatic stresses (i.e. large-scale bleaching, including climate change effects) and local factors (e.g. overfishing, eutrophication, pollution, etc.); identify and locate the coral reefs with potential for restoration given site-specific conditions, historical causes of degradation, and prioritizing sites where coral reef restoration could reduce coastal erosion and/or flooding.

(2) Conduct an assessment of the technical, economic, and institutional opportunities and risks of large-scale coral reef restoration, including the technical options, lessons learnt in reef restoration in the Seychelles and elsewhere, as well as local legal, regulatory, and institutional constraints and opportunities for bringing coral reef restoration to scale. These techniques may include established technologies and practices of restoration, but also considered other innovative approaches and hybrid approaches such as artificial reefs.

(3) Develop detailed financing and implementation strategies for large-scale reef restoration relying partly or fully on private financing sources and public-private partnerships, based on the assessments conducted under (1) and (2) above.

1.2 Project Aims

Ultimately this project aimed to deliver the following outcomes:

- Recommendations for the sustainable upscaling of coral reef restoration for the reduction of coastal erosion and flood risk.
- Identification and feasibility assessment of the full range of possible techniques, technologies and solutions for coral reef restoration at scale, in one or two focus areas, given the assessed risks and opportunities (also with regard to institutional, socio-economic and environmental factors).
- Identification of innovative and sustainable financing options for coral restoration, including the role of public, private and non-governmental organization.

1.3 Purpose of this Report

This report presents a consolidated overview of the entire project, including identifying the ecological potential and risks of coral reef restoration. Existing information and rapid surveys at two focus sites (i.e. case studies) were considered in the context of the environmental requirements, limitations and the risks of large-scale restoration in those areas. From this, we developed a simple framework to help determine the ecological potential for coral reef restoration at the various locations and to identify any risks involved. This framework was used to identify priority areas for future coral restoration.

We then identified and assessed costs and benefits of reef restoration in the Seychelles. presenting a guidance framework for undertaking economic assessments of reef restoration in the Seychelles. We used the guidance framework, to undertake a desktop economic assessment of the two study sites – La Passe (La Digue) and Au Cap (Mahé) – using available data and information, including from this study. The desktop economic assessment was used to select locations for a detailed case study. We used available knowledge to identify priority locations for reef restoration. Highest priority was assigned to hose location where coral restoration alone had a high potential of achieving outcomes. However, we recognised that there were a number of other locations where coral restoration had potential for success and where restoration could support coastal management objectives if restoration was combined with engineering solutions. These medium priority locations were also included in the overall business case and assessment of their importance to the Seychelles coastal communities and economy.

Task 3 of the study focuses on the identification and presentation of a business case for large-scale coral reef restoration in Seychelles. The business case was developed through stakeholder consultation with key experts in the Seychelles, a review of similar approaches taken elsewhere, a high-level financing assessment framework and the economic evaluation.

This report documents the methodology, results outcomes and recommendations of this project. It provides strategic direction for coral reef restoration in the Seychelles and identifies costings, governance arrangements and finance mechanisms.

2 Locational Context

2.1 Overview

The Republic of Seychelles is an island archipelago located in the Indian Ocean, approximately 1600 km east of Kenya (Figure 2-1). It comprises around 115 islands with, 42 being granitic in nature and the rest of coralline origin. Mahe is the largest island (~157 km^2), and the location of the capital of the Seychelles, Victoria. Most of the population are based on the granitic islands, with few residing on the very low lying, and generally freshwater free, coral islands. The Seychelles is located within the equatorial region and, although not directly affected by cyclones, they do receive the effects of seasonal trade winds, rains, large swells and storm surges.

The population of the Seychelles is around 95,000, most of which live on Mahe (79%), Praslin (9%) and La Digue (4%) (National Bureau of Statistics 2015). The Seychelles economy depends heavily on tourism and fishing. The Seychelles tourism sector contributed 46.1% of the country's GDP in 2010, and directly provided for 56.4% of national employment. In 2010, tourism generated $US 382.5 million of foreign exchange, or 33.2% of the country's foreign exchange earnings. In actual fact, the contribution of tourism to the national economy is much more significant, since these statistics do not account for the economic multiplier effect that is spawned by the industry and the creation of value added in other sectors (National Bureau of Statistics 2018).

2.2 Climate Change Factors

The effects of climate change in the Seychelles are projected to result in increased temperatures (on land and in the ocean). There are also likely to be increased ocean acidity, changes to rainfall patterns (causing flash flooding and erosion) and continued sea-level rise. There are significant implications from the effects of climate on coral reefs and the ecosystem services they provide for the Seychelles. Most notably, these ecosystem services include coastal protection, food security, tourism, fisheries and biodiversity benefits.

Observed climatic changes to date show that mean annual temperatures over Seychelles Islands have increased at an average rate of 0.11˚C per decade over the period 1960–2006. The observed daily data available is insufficient to determine long-term trends in temperature extremes such as 'hot' or 'cold' days and nights. The annual rainfall over the main granitic islands is increasing; annual trends on Mahé for the period 1972 to 2006 showed an increase of 13.7 mm per year. This increase is not evenly distributed across the year, but rather is attributable to a few heavy rainfall events; however, observations are insufficient to identify long-term trends in rainfall extremes. Observed changing seasonal patterns bring harsher storms with more intense rainfall, and longer dry spells. Extreme tide levels in the last few years have destabilised the coastline. Significantly increasing wind speed trends have been observed during the September-October-November months; and mean annual sea surface temperatures surrounding Seychelles show a statistically significant increasing trend of 0.16˚C per decade for the period 1960–2006 (Ministry of Home Affairs, Environment, Transport and Energy 2011).

Projected future climatic changes suggest annual temperature increases will be between 1.2˚C and 3.4˚C by the 2080s. Projections indicate increases in the frequency of 'hot' days and nights, with the number of cold days and/or nights dropping to 'few to none' towards 2080. The increase in dry spells that resulted in drought conditions in 1999 and the 1998 mass coral bleaching foreshadow likely events under future climate change. The frequency of coral bleaching events is projected to increase as seawater temperatures continue to rise. Global average sea- level rise projections at a high emission scenario increases of 42-85 cm by 2100 (Ministry of Home Affairs, Environment, Transport and Energy 2011).

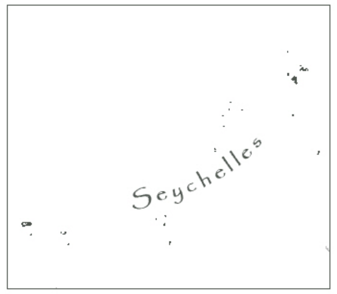
In brief, with respect to rainfall, predicted changes suggest heavier rains interspersed with longer dry periods. Together with increasing temperature and ocean acidity, these are likely to have significant impacts on the Seychelles coastal ecosystems and reef communities. For example, coral bleaching, which is already threatening reef ecosystems in the Seychelles, is likely to occur more frequently. The associated break down of coral will expose the coastline to more wave energy which, together with the higher sea-level, will have a significant impact on low lying areas and beaches (Ministry of Home Affairs, Environment, Transport and Energy 2011).

2.3 Other Drivers

Coral reefs occur around the granite islands as well as at the coralline islands, and are a major focus of the tourist trade. The reefs were significantly affected following a major coral bleaching event in 1997/1998 as a result of a very strong El Niño event, during which about 90% of the coral around the main islands died.

The coral reefs help to reduce erosion of parts of the islands, and the loss of coral following the bleaching event had an impact around the Seychelles.

Coral reef health in the Seychelles has also been affected by overfishing, land-based runoff and by the impacts of tourism, although these are minimal compared with the impacts of bleaching. In addition, Crown-of-thorns starfish populations have occasionally increased to nuisance numbers, causing extensive damage to the reef.



LEGEND

Seychellois Exclusive Economic Zone

Title:

Locality Map

Figure: 2-1

Rev: A

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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3 Task 1 Methodology

This section outlines the methods utilised to address Task 1 of this project, 'Identifying the Ecological Potential and Risks of Coral Restoration'. It is comprised of the following sub-tasks, which are described below:

(1) Identifying, collating and evaluating existing information for key focus areas in the Seychelles, noting ecological attributes, key environmental values and associated risks. This was done through a review of existing information, expert workshop and stakeholder engagement.

(2) Targeted ecological field surveys at two focus sites.

(3) Experts workshop and stakeholder engagement.

3.1 Evaluation of Existing Ecological Information and Associated Restoration Risks

Detailed collection of new data was not intended for this project. Rather, the assessment primarily relied on a combination of available data, existing knowledge and other information for the three islands of Mahe, La Digue and Praslin, together with additional knowledge and expert opinion from experts and local stakeholders (refer Section 3.2 below). This information was used to develop an understanding and relevant mapping of causes of degradation and condition of reefs. This enabled an understanding of the local factors that affect reef condition, and an improved understanding of the areas where reef restoration has potential, and where the maximum (multiple) benefits from reef restoration can be achieved.

This overarching desktop assessment was augmented with a more focussed investigation at two key sites (case studies), which acted as field validation test sites where environmental reef surveys were conducted, including the collection of ecological data. Satellite and drone imagery was also examined for these sites and surrounds (e.g. adjacent land). The two sites selected for these field surveys are Au Cap (Mahe) and La Passe (La Digue). Field survey methodologies for these sites are detailed in Section 3.3.

Data were collated for all key ecological indicators, where this information was available, to determine reef condition and restoration potential and/or risks (e.g. identify suitable sites for further restoration consideration). Key data sources for each of these ecological indicators and/or restoration risks is also indicated (Table 3-1). It is noted that gaps exist, especially for bathymetry and hydrodynamic conditions.

Where data gaps existed, proxies were used where practicable to help estimate certain variables. For example, catchment development, land clearing, proximity of rivers and creeks may be used to identify low or poor water quality entering the coastal system. Shoreline vegetation can be an ecological indicator of shoreline stability, and planned coastal works can highlight erosion hotspots.

The information consolidated from all of the above was considered in the context of the environmental requirements, limitations and the risks of large-scale restoration in those areas. From this, we developed a simple framework to help determine the ecological potential for coral reef restoration at the various locations, and to identify any risks involved. This framework supported the identification of priority areas for future coral restoration.

Table 3-1 Indicators for ecological information and associated restoration risks, noting sources of data for each focus site

Indicator	Data source Au Cap	Data source La Passe
Bathymetry	*Not collected*	*Not collected*
Roughness	Seychelles Meteorological Authority data used to report dominant wind strength and direction at Seychelles Airport	Seychelles Meteorological Authority data used to report dominant wind strength and direction at Seychelles Airport
Health condition of the reef	RRA	RRA
Hydrodynamic conditions	*Not collected*	*Not collected*
Meteorological conditions	SMA	SMA
Historic coral reef condition	Taylor study supplemented by historical data from Nick Graham	No data
Substrate type	RRA	RRA/GEF report
Water quality	Unisey collected and analysed	Unisey collected and analysed
Biological stressors	RRA	RRA
Site accessibility	Photos taken by field team	Photos taken by field team
Herbivorous fish	RRA	RRA
Algal cover	RRA	RRA
SST	NOAA	NOAA
Shoreline vegetation	Photos taken by field team	Photos taken by field team

We used available knowledge to identify priority locations for reef restoration. Highest priority was assigned to those locations where coral restoration alone had a high potential of achieving outcomes. However, we recognised that there are a number of other locations where coral restoration had potential for success and where restoration could support coastal management objectives if restoration was combined with engineering solutions. These medium priority locations were also included in the overall business case and assessment of their importance to the Seychelles coastal communities and economy.

3.2 Experts Workshop and Stakeholder Engagement

3.2.1 Expert Workshop Basis

Following collation of an initial information base and completion of a first pass risk analysis, we conducted a virtual workshop between project team experts. This workshop enabled testing of the validation and assumptions across the initial analysis and assessments. Participants were provided with initial assessments prior to the meeting, which helped to facilitate discussions around understanding pressures and responses on local coral reefs, the ecological services they provide, and the implications in the context of climate change, community resilience building and restoration considerations. Outputs from the workshop were incorporated into the outcomes of this report.

3.2.2 Key Stakeholders for Engagement

The key local stakeholders engaged during the course of this project are listed in Table 3-2, covering government departments, non-governmental organisations (NGOs), and other organisations (particularly key tourism stakeholders).

One-on-one engagement occurred at varying intensities, commensurate with the needs of the various project activities.

Table 3-2 Key Stakeholders which were engaged at various stages of the project.

Key Stakeholder	Form of engagement
NGOs	
Nature Seychelles	Invited to mid stage workshop
Island Conservation Society	
GVI Seychelles	
Green Islands Foundation	
Seychelles Islands Foundation	
Government Departments/Agencies	
Ministry of Environment, Energy and Climate Change	
Department of Environment	
Seychelles National Parks Authority	Took part in the mid stage workshop
Ministry of Tourism, Civil aviation, ports and marine - tourism dept	
Ministry of Finance, Trade Investment and Economic Planning	
Seychelles Trading Commission	
GIS Centre	
Other	
Independent Consultant	Invited to mid stage workshop
Seychelles Hospitality and Tourism Association	Invited to mid stage workshop
Jan Robinson, SWIOFish	Phone interview, follow-up emails and data/information
Jules Seidenberg, Global Climate Change Alliance +	Phone interview, follow-up emails and data/information
Helena Sims, The Nature Conservancy (TNC) Seychelles	Phone interview, follow-up emails and data/information
Angelique Pouponneau, SeyCCAT	Phone interview, follow-up draft review of draft report
Andy Rylance, UNDP	Phone interview, follow-up emails and data/information
Herve Barois, BioFin	Phone interview, follow-up emails and data/information

Key Stakeholder	Form of engagement
Additional stakeholders engaged with email exchanges only (limited input)	
Pugazhendhi Murugaiyan, CAMS	Email exchanges
Peter Brinn, Global Climate Change Alliance +	Email exchanges
Elke Talma, PCU Seychelles	Email exchanges
Roland Alcindor, UNDP	Email exchanges

3.3 Reef Field Survey Methods

The only field data collection element of Task 1 was to conduct rapid reef assessment (RRA) surveys and water quality analysis at the two focus sites. We employed a rapid reef assessment survey methodology that uses methodology adapted from that recommended by the Global Coral Reef Monitoring Network. It is a broad-scale method with only a low precision, but is appropriate considering the time and financial limitations of this project. This methodology relies on data acquired by divers operating on snorkel and is described in brief below.

Reef surveys were conducted from December 2018 to January 2019.

3.3.1 Reef Survey Aim

To collect data on the following indicators:

- Herbivorous fish/urchins;
- Vegetation/Algal cover (Turf/Macro/Coralline/Seagrass);
- Health condition of the reef (categorical based on data from other indicators – including live hard coral cover (LHCC), disease, bleaching etc.); and
- Substrate type.

3.3.2 Reef Survey Sites

Field investigations were focussed on sites at Au Cap (Mahe) and La Passe (La Digue). In line with the request and advice from World Bank, the preference is to omit the Anse Royale site from field work at this stage.

Au Cap was highlighted by the World Bank team at the inception meeting of the project as a location that would be a good focus site. The area chosen (circled in yellow in Figure 3-1) is opposite an area of high coastal erosion.

In Annex 2 of the original World Bank TOR document, it stated the following with respect to focus areas: *'La Passe (La Digue): erosion and accretion by breakwaters and anchorage sites, in close proximity to shallow and wide coral reefs.'* The selected La Passe site (circled in red in Figure 3-2) is in line with this description of the focus site and is opposite an area undergoing active erosion.

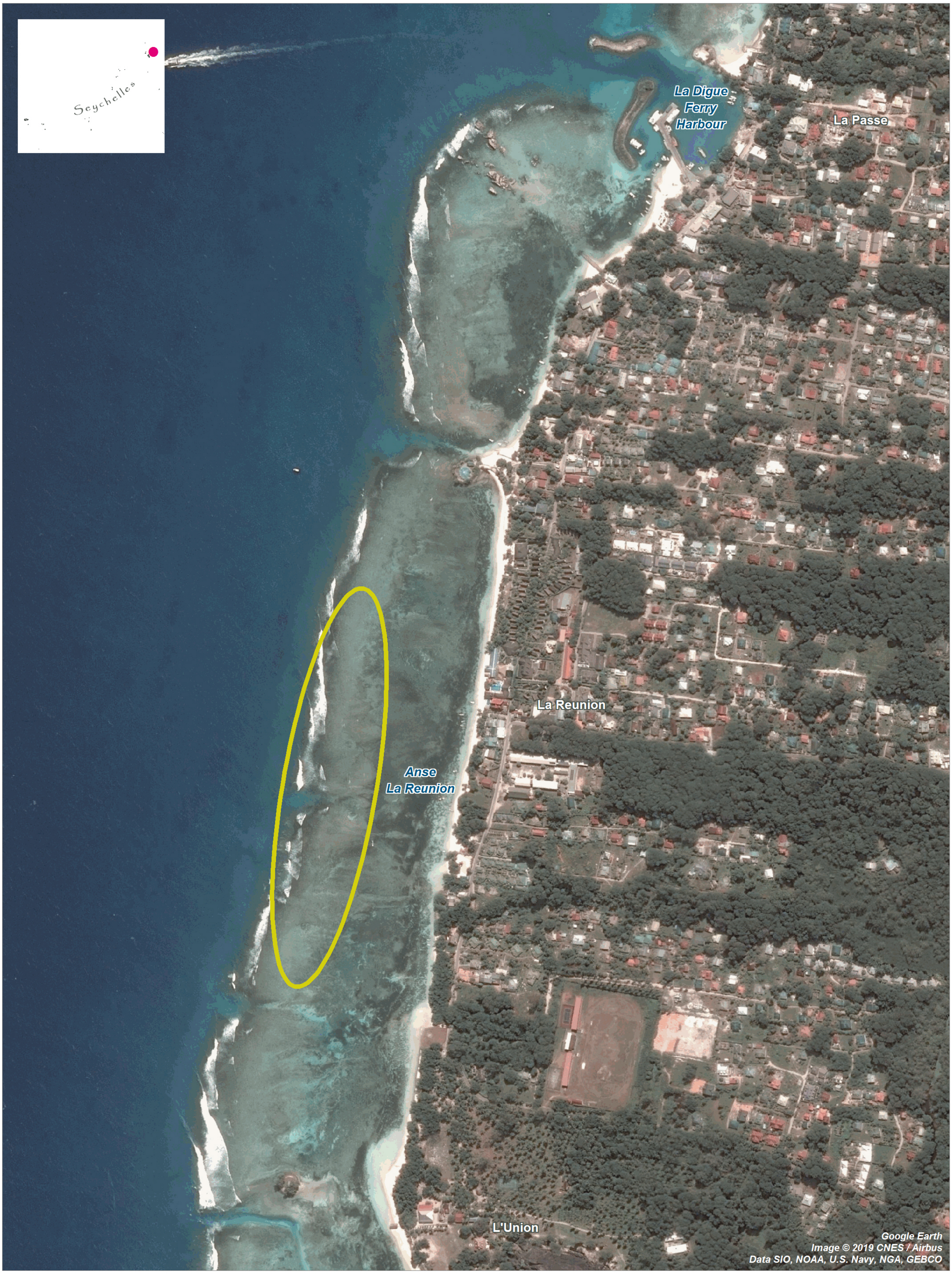
Title:	Figure:	Rev:
Au Cap (Mahe) - field survey site marked by yellow circle	**3-1**	**A**

N

0 200 400m
Approx. Scale

BMT
www.bmt.org

Filepath: I:\B23338_I_JLB World bank Seychelles Coral DR\DRG\ECO_005_190208_Reef Survey Site Au Cap Mahe.WOR



Title:

La Reunion (La Digue) with proposed site marked by yellow circle

Figure: **3-2**

Rev: **A**

N

0 150 300m

Approx. Scale

www.bmt.org

Filepath: I:\B23338_I_JLB World bank Seychelles Coral DR\DRG\ECO_006_190208_Reef Survey Site La Reunion La Digue.WOR

3.3.3 Sampling Methodology

Each snorkelling pair completed four (4) timed swims (eight in total) of 10 minutes, parallel to shore within the area of the focus site as shown in Figure 3-1 and Figure 3-2, being careful not to survey the same area twice. Each snorkelling pair was at least 20m apart from each other on all swims.

The first snorkeler in each pair counted the number of herbivorous fish and urchins observed in the 10 min timed swim. The area sampled was approximately 20 m wide, or 10 m on either side of the observer. Herbivorous fish taxa groups/species counted were – Surgeonfish/Bristletooth/Tang, Parrotfish, Rabbitfish, Angelfish, Batfish, Orange-spined unicornfish. Urchin family groups counted were: *Diadema, Echinometra, Tripneustes, Echinothrix*. The turbidity of the water was also noted at the beginning and end of the timed swim.

The second snorkeler in each pair collected data on the benthic community. At every two minute interval of the 10 minute timed swim, the snorkeler stopped and recorded the percentage of live hard coral cover as per the categories shown in Figure 3-3, as well as the percentage of substrate (Rock, Rubble, Sand, LHCC, Standing Dead Coral, Seagrass), and the percentage of algae (Turf/Macro/Coralline) in a 7m diameter area below them. They also recorded any presence of coral disease, bleaching or coral predators (Cushion star, *Drupella* sp., Crown-of-Thorns starfish.).

Photos were taken of the habitat/substrate at every two minute interval of the 10 minute timed swim, as well as of any other flora/fauna of interest or coral reef health indicators.

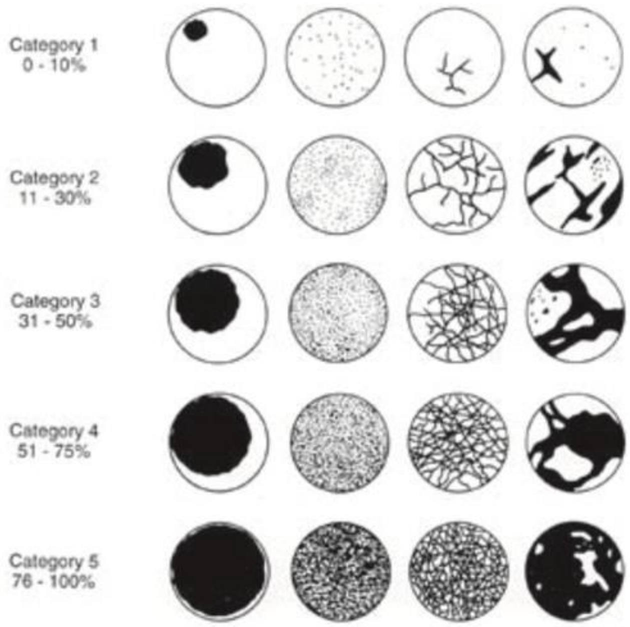


Figure 3-3 Visual estimation categories for percent coral cover from Dahl (1981) in English et al. (1997)

4 Field Survey Results – La Digue and Au Cap

Data were collected and collated for a number of indicators, as described in Section 1, and the results of these are listed in this section. Unfortunately, data for the following indicators could not be sourced for the sites visited:

- Bathymetry;
- Hydrodynamic conditions; and
- Roughness.

4.1 Historical Reef Condition

No data sources could be found for the historical reef condition of the La Passe (La Digue) site. For the Au Cap (Mahe) site data were sourced from Graham et al. Their data from 1994 cited a Live Hard Coral Cover (LHCC) of 19.2% and structural complexity of 3.6/5. It should be noted that the data from 1994 were collected prior to the mass global bleaching event of 1998, which led to an approximate coral mortality rate of 95% across the reefs of Seychelles.

4.2 Substrate Type

To estimate the substrate type for each site Rapid Reef Assessment surveys were conducted. GPS coordinates for the two sites were as follows:

- Au Cap, Mahe: 4°43'5.14"S, 55°31'39.01"E.
- La Passe, La Digue: 4°21'28.90"S, 55°49'23.68"E.

Results from these surveys for the two sites are shown in Table 1. Shallow subtidal reef flats at Au Cap were mostly dominated by rubble substrate (67.5%), followed by rock (19.8%) and sand (13.5%). There was very little live hard coral cover (LHCC, 3.6%) or standing dead coral (0.5%). The dominant substrate at La Passe was bedrock (59.5%), although a lot of rubble was also present (57.3%) and to a lesser extent sand (32.4%). There was very little LHCC (1.5%) and no standing dead coral was observed (Table 4-1). In addition, photos in Figure 4-1 and Figure 4-2 give an indication of the substrate types found at the two sites.

Table 4-1 Mean substrate type (%) for two focus sites

Site	Rock	Rubble	Sand	Live Hard Coral Cover (LHCC)	Standing dead coral
Au Cap	19.8%	67.5%	13.5%	3.6%	0.5%
La Passe	59.5%	57.3%	32.4%	1.5%	0%

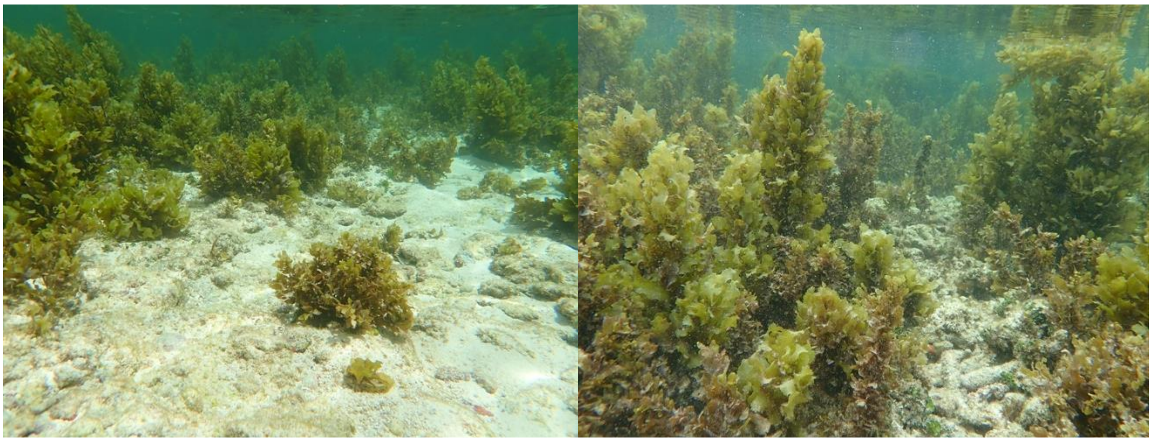


Figure 4-1 Examples of substrate type at Au Cap, Mahe, showing rubble as the predominant substrate

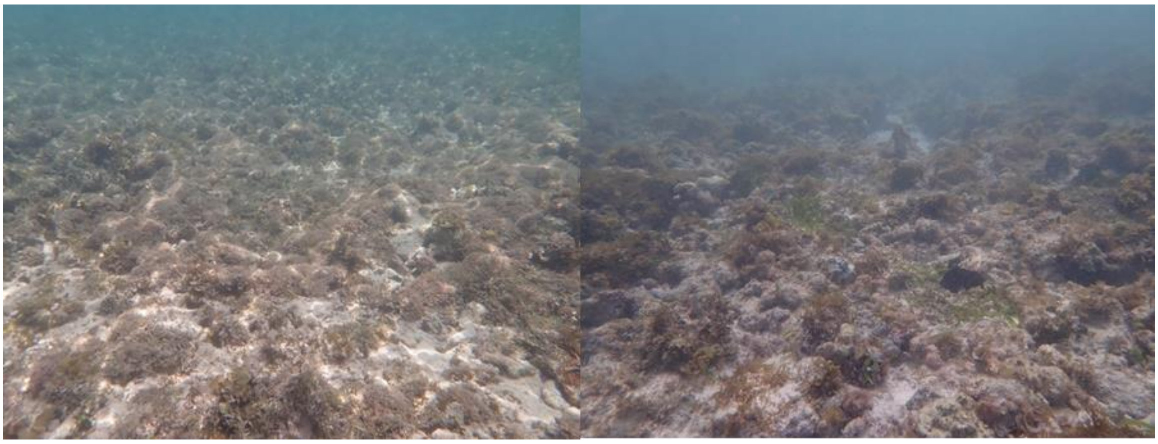


Figure 4-2 Examples of substrate type at La Passe, La Digue, showing bedrock and rubble as the predominant substrates

4.3 Vegetation/Algal Cover

Vegetation cover was high at both sites. Shallow reef flats at Au Cap were dominated by macroalgae, specifically Sargassum sp. (Figure 3) with a mean cover of 45.5%, while turf algae and crustose coralline algae (CCA) were less abundant and seagrass was not recorded (Table 4-2 Mean subtidal vegetation cover (%) for two focus sites), although is present closer to the shoreline. In contrast, seagrass was the dominant vegetation cover at La Passe (47%), followed by turf algae (34%), macroalgae (11%) and CCA (1%). In addition, the site at La Passe was dominated by extensive zoanthid mats (21%) (Figure 4).

A detailed spatial habitat map of La Passe was produced by Artelia (2017) and is provided as Figure 4-5 below. This provides an overview of the broadscale distribution of macroalgae and seagrass vegetation at the site.

Table 4-2 Mean subtidal vegetation cover (%) for two focus sites

Site	Macroalgae	Turf	Crustose Coralline Algae (CCA)	Seagrass
Au Cap	45.5	8	1.5	0
La Passe	11	34	1	47

Figure 4-3 Macroalgae, almost entirely Sargassum sp., dominated the shallow subtidal reef flats at Au Cap (Mahe)

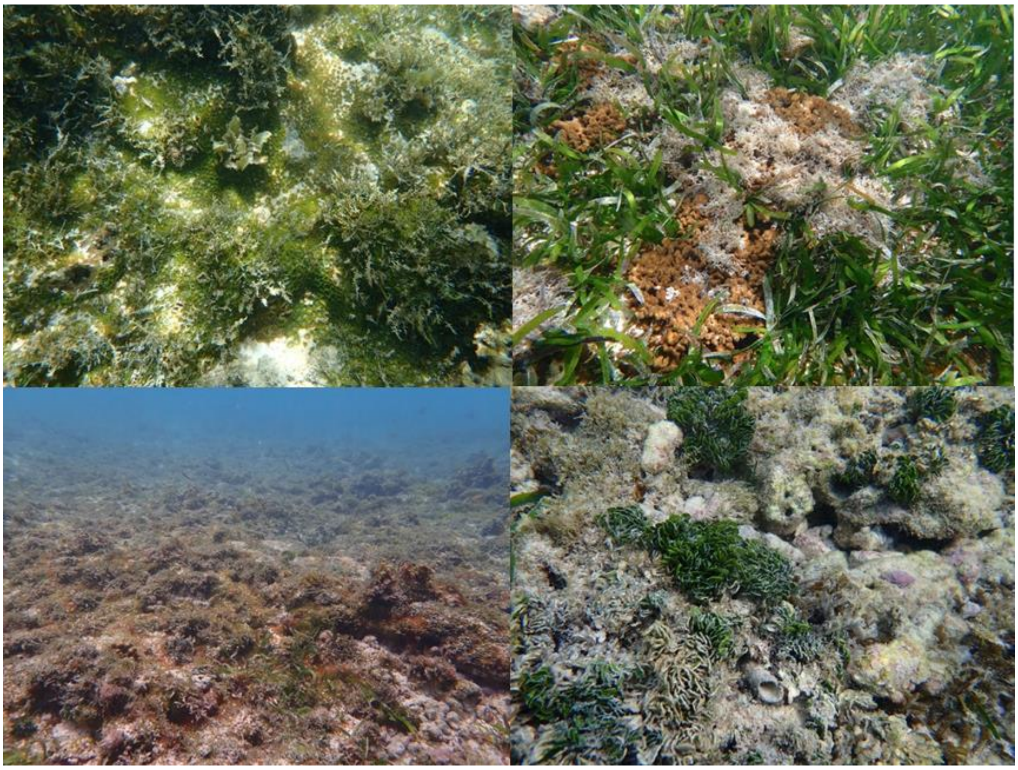


Figure 4-4 Turf algae, zoanthid mats and seagrass were dominant on shallow subtidal reef flats at La Passe (La Digue)

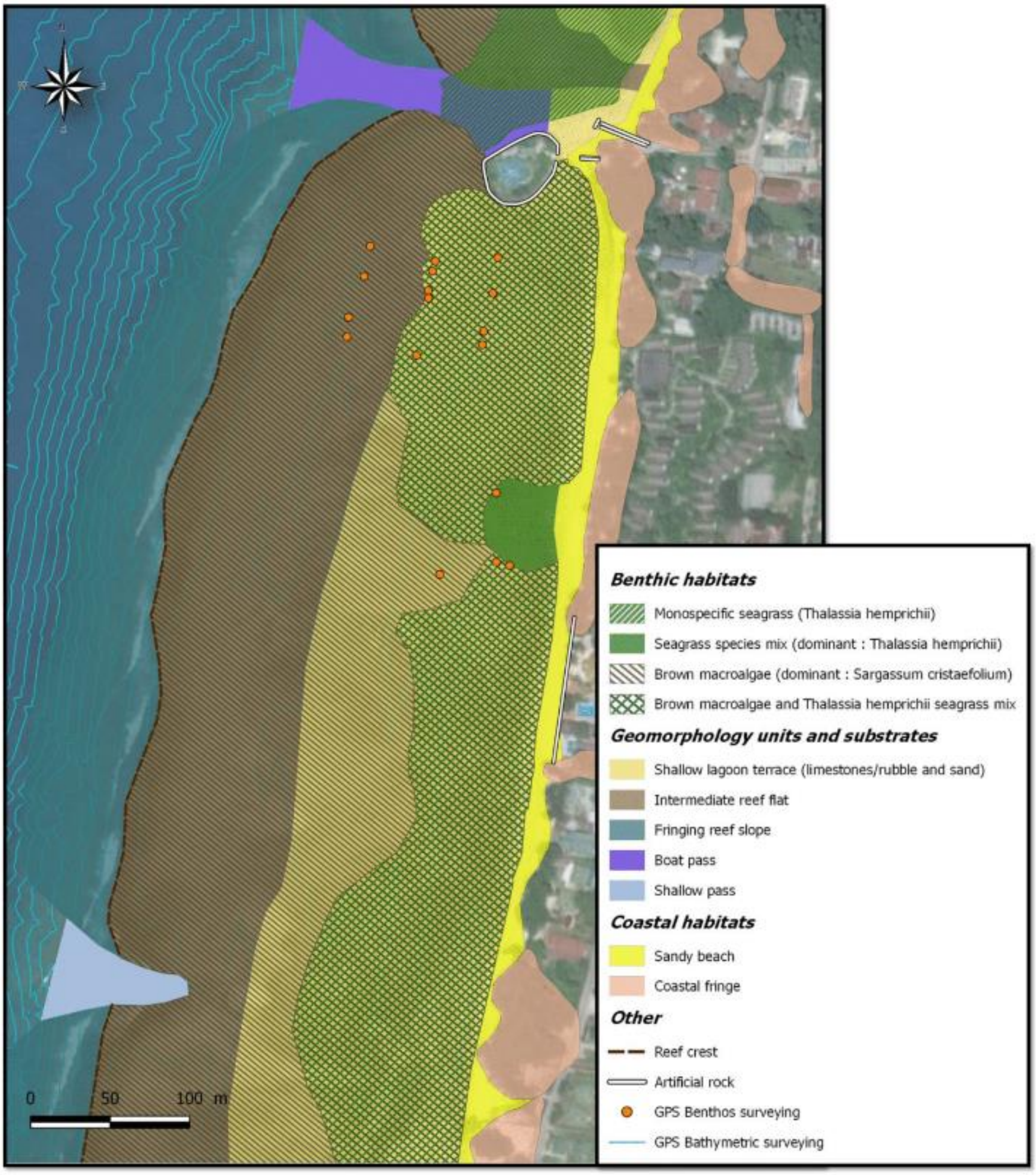


Figure 4-5 Benthic communities and geomorphological mapping units, La Digue (source: Artelia 2017)

4.4 Herbivorous Fish and Urchins

Data were collected on herbivorous fish and urchin species during the RRA surveys (Table 4-3). Herbivorous fish at Au Cap included mainly Rabbitfish and Parrotfish, while very few herbivorous fish were observed at La Passe, despite no direct fishing activity observed during the field visit. Urchins were abundant at both sites, with a large number of *Diadema* spp. and *Echinothrix diadema* at Au Cap, whereas *Echinometra mathaei* and *Tripneustes gratilla* were more abundant at La Passe.

Table 4-3 Total no. of fish and urchins counted during RRA surveys at both focus sites

Site	Urchin species				Herbivorous fish		
	Diadema spp.	*Echinothrix diadema*	*Echinometra mathaei*	*Tripneustes gratilla*	*Parrotfish*	*Surgeonfish*	*Rabbitfish*
Au Cap	213	159	1	6	32	0	33
La Passe	2	41	116	42	0	8	0

4.5 Water Quality

Two samples of 250 ml of water were collected at the reef crest at each of the two focus sites. Levels of Dissolved Oxygen (DO) were tested using the Vernier Dissolved Oxygen probe (Labquest logger lite software). Salinity was tested using the Vernier Salinity probe (Labquest logger lite software), and Phospate levels were tested using the Hach Lange DR1900 VIS Spectrophotometer. Levels of Nitrate could not be tested for as the Spectrophotometer could not be calibrated for seawater, therefore the high levels of chloride would interfere with the results.

The high percentage of DO (Table 4-4) is not surprising given the water movement that occurs on shallow subtidal reef flats adjacent to the reef crest. Highly oxygenated water is an important factor in coral growth. Corals prefer levels of salinity between 32-34 ppt for successful reproduction and growth. The levels of salinity in Seychelles vary from 29-34 ppt, and the results we obtained fall within this range.

Table 4-4 Results of water quality parameters for samples collected at two focus sites

Site	Dissolved Oxygen (DO)	Salinity	Phosphate (PO_4^{3-})
Au Cap	8.8mg/l 125%	33.4 ppt	0.17mg/l
La Passe	12.2mg/l 150%	34.2 ppt	0.57mg/l

4.6 Biological Stressors

The presence of biological stressors such as Crown-of-Thorns Starfish (COTS) and Drupella snails were not observed at either site. No recent feeding scars were observed either.

4.7 Health Condition of the Reef

The condition of the reefs at the two sites is considered to be poor (very low live coral cover compared to other species and bare rock). The large quantities of rubble have not been significantly colonised and there is little live coral. There are large extents of algal cover on the few live corals seen. There was little evidence of recently dead coral at the two sites and the poor condition is likely to be due to a lack of response following the significant bleaching events which have occurred in the past. There is a large expanse of bedrock at each site which provides ideal surface for recruitment by CCA and then corals, but this has not occurred. However, most of this bedrock is now colonized by turf algae or macroalgae. There are few herbivorous fish which may be leading to greater algal cover which also impacts coral recruitment. The close proximity of these sites to land means that runoff of nutrients and sediment can occasionally be an issue.

This is consistent with the findings of Artelia (2017) who reported the La Digue area to be stressed as a result of continued runoff of poor-quality water from the urbanised foreshore, and possibly sewage. They also suggested that the impacts of climate change together with these additional stressors would have a long-term negative effect on the health state of the local marine ecosystem. La Digue was suggested to presently have a low to medium ecological sensitivity to external pressures; play important roles in stabilising sediment; and provide high functional value as fish habitat (Artelia 2017).

4.8 Sea Surface Temperature (SST)

Average SST for both sites was taken from https://www.seatemperature.org/africa/seychelles/ whose data are based on NOAA readings (Tables 4-5 and 4-6).

Table 4-5 Monthly minimum and maximum Sea Surface Temperature for La Digue

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min ºC	27.3	27.5	28	29.2	27.6	25.7	25	25.2	26.5	27.3	26.9	26.9
Max ºC	29.6	29.9	30.8	30.7	30.8	29.2	28.3	27.9	28.9	29.4	29.7	29.5
Min ºF	82	82.5	83.5	85.1	83	79.6	78.3	78.4	80.7	81.9	81.5	81.5
Max ºF	84.3	84.9	86.3	86.6	86.2	83.1	81.6	81.1	83.1	84	84.3	84.1

Table 4-6 Monthly minimum and maximum Sea Surface Temperature for Mahe

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min ºC	27.5	27.4	28	29.1	27.3	25.6	24.8	24.9	26.2	27	26.9	26.9
Max ºC	29.4	29.9	30.7	30.5	30.9	28.9	27.9	27.5	28.7	29.3	29.6	29.5
Min ºF	82.2	82.3	83.4	84.9	82.6	79.4	77.8	77.9	80.1	81.5	81.5	81.5
Max ºF	84.1	84.8	86.1	86.3	86.2	82.7	80.9	80.5	82.6	83.8	84.2	84.1

4.9 Meteorological Conditions

Predominating winds in the Seychelles are south-easterly trade winds which occur during the dry monsoon season (May – October). These winds account for almost 50% of the wind experienced in

Seychelles (Figure 4-6), with wind speeds generally between 4-10m s^{-1}. Westerly and north-westerly trade winds occur during the wet monsoon season (December – February), although only make up about 25% of the annual winds.

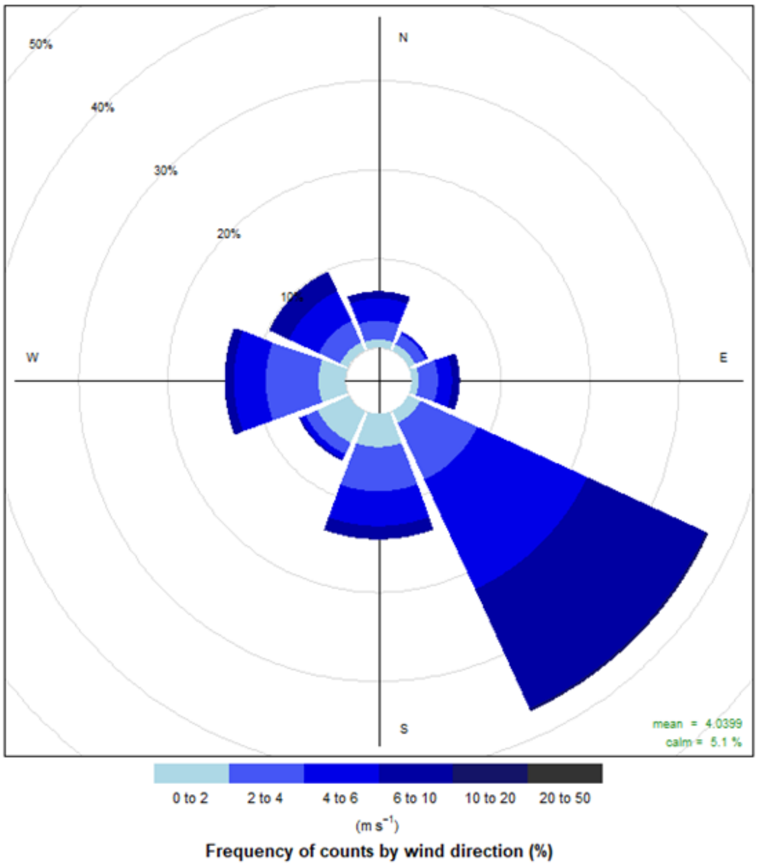


Figure 4-6 Windrose showing the dominant wind direction and wind speed at Seychelles International Airport from 2010-2018. Data provided from Seychelles Meteorological Agency.

4.10 Site Accessibility

Access to both sites by snorkelling is relatively easy from the shoreline as entry can be made straight from the beach, and the road is a short distance away (<20 m). This provides access to the reef flat area in front of the reef crest, which is not accessible by boat at low tide. To access the reef slope (i.e. the reef beyond the reef crest), a boat is required and this can be done at both low and high tide, as there are channels for boats nearby.

4.11 Shoreline Vegetation

The shoreline vegetation varied between the two focus sites. At La Passe there was discontinuous vegetation with some shoreline stabilization provided by Badamier (*Terminalia catappa*), Mahoe (*Thespesia populnea*) and Takamaka (*Calophyllum inophyllum*) trees (Figure 4-7). There were also large areas with only sand present, as well as some shoreline rock armouring, presumably as a coastal erosion preventative measure.

At Au Cap there was relatively little shoreline vegetation, with the majority of the shoreline stabilized by a concrete sea wall (Figure 4-8).

Figure 4-7 Shoreline vegetation at La Passe (La Digue) focus site

Figure 4-8 Shoreline vegetation and development at Au Cap (Mahe) focus site

4.12 Historical and Planned Coastal Works

Information gathered from the Coastal Zone Management Plan for the two areas provide recommended management options for the coastline at the two locations. The recommendations are focussed on soft ecosystem-based solutions.

La Passe

- Permeable groins can be used to stabilize beach areas.
- Interventions with shoreline hardening should be avoided.
- Reef conservation and maintenance of the underwater bathymetry to avoid further degradation. In this light, detailed bathymetry data are available for the La Digue site (Artelia 2018), as shown in Figure 4-9. Loss of reef complexity and bathymetric features can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.
- Watershed management is critical to maintain healthy reefs (ridge to reef based management).

Au Cap

- It is recommended to stabilise the shoreline with living shorelines and vegetation, with potential small beach stabilisation techniques if needed.

- Hardening of the shoreline to reduce erosion should be complemented with other stabilisation techniques. like small beach stabilisation or vegetated living shoreline. to permit sediment transport in the reef lagoon.
- Because the reef provides substantial protection, reef conservation and maintenance of the underwater bathymetry to avoid further degradation. Loss of reef complexity and bathymetric features can lead to more wave action and flooding and thus enhanced sediment transport and coastal changes.

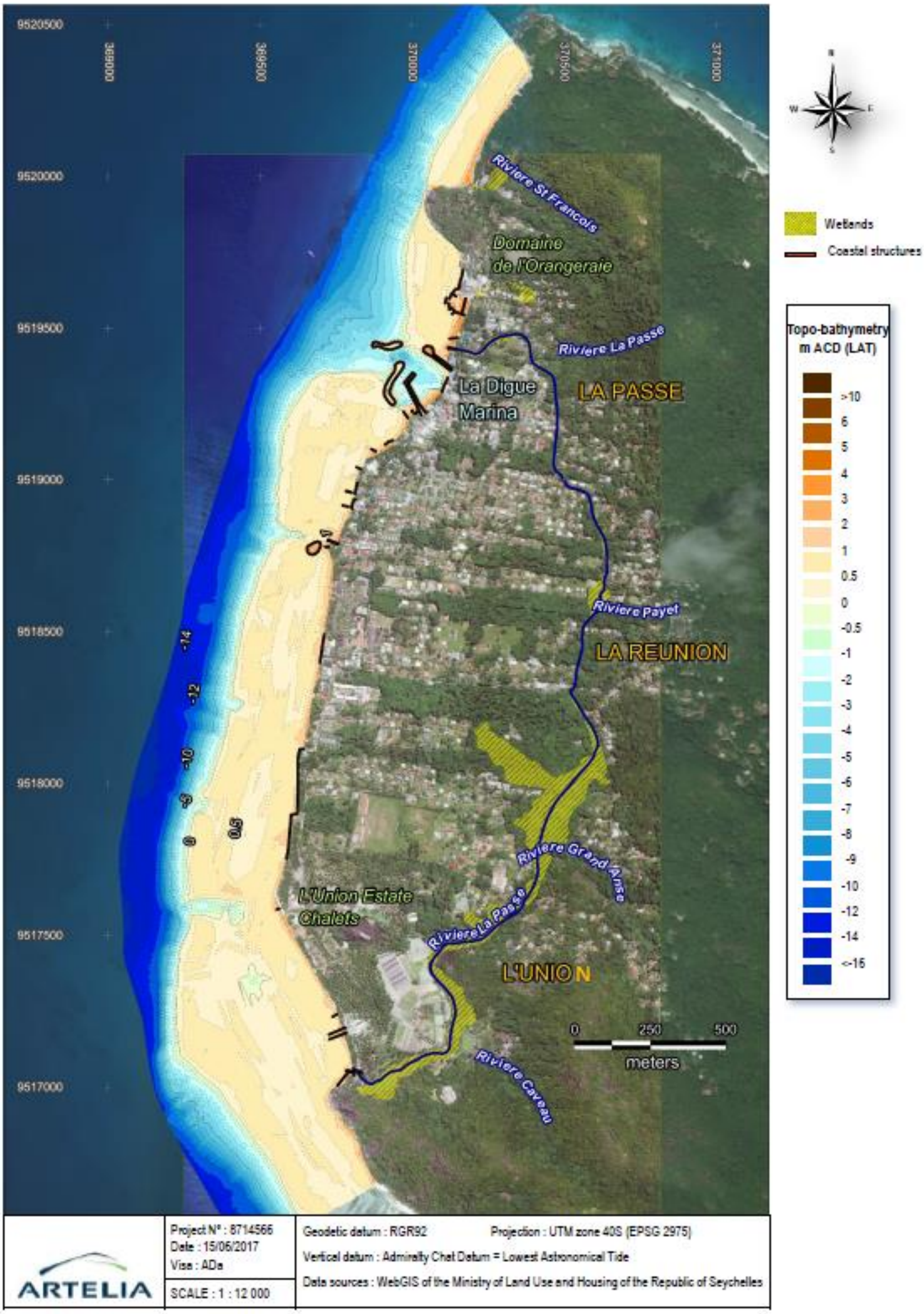


Figure 4-9 Bathymetry at La Digue (source: Artelia 2018)

5 Review of Coral Restoration Techniques and Approaches

Future restoration decisions will be better informed if decision makers (i.e. those using the restoration framework to guide reef restoration investments) are aware of, and familiar with, the range of restoration techniques available to them. Note that there are a range of restoration techniques available, each with inherent advantages and disadvantages. Some may be more suitable to certain environmental conditions or desired restoration outcomes, and they may also require differing resources or levels of expertise.

In the following sections we present an overview of the various coral restoration techniques. And broad restoration strategies most commonly used, from both a global perspective and local Seychelles perspective. These typically include:

- Artificial reefs;
- Coral gardening and transplantation (including fragmentation and micro-fragmentation) (including both marine nurseries and land-based farms);
- Larval restoration;
- Physical substrate modification (e.g. stabilisation); and
- Indirect restoration (e.g. water quality improvements) to better facilitate natural recruitment.

The information presented here is based on information obtained from peer reviewed and grey literature. Information captured includes (where available):

- Type of restoration process;
- Outline of approach and location;
- Brief description of method (including an indication of the technical complexity and skills required);
- Results (e.g. success rates);
- Information on the advantages and disadvantages of the approach; and
- Resources required (e.g. work force, materials, technology, financial).

5.1 Global Overview

We provide here a literature review of the primary existing reef restoration methods for the purposes of provider broader context to the available options. This addresses not only the existing industry but potential future industry applications (i.e. many of this remains in research/trial phases, as opposed to commercial or mainstream applications). A further tabulated summary of the data sources used is provided in Appendix F.

By way of introduction, reef restoration remains and evolving field with new approaches and concepts continuing to emerge. Smith and McLeod (2018) provide an indicative chronology of the introduction of the most common reef restoration approaches. More recent developments at the cutting edge of reef restoration research include approaches such as: coral rubble stabilisation, harvesting coral spawn slicks and reseeding at large industrial scales, next-generation three-dimensional settlement surfaces, improving the thermal tolerance in coral recruits, and semi-mechanised coral out-planting. The more common, established techniques are outlined below.

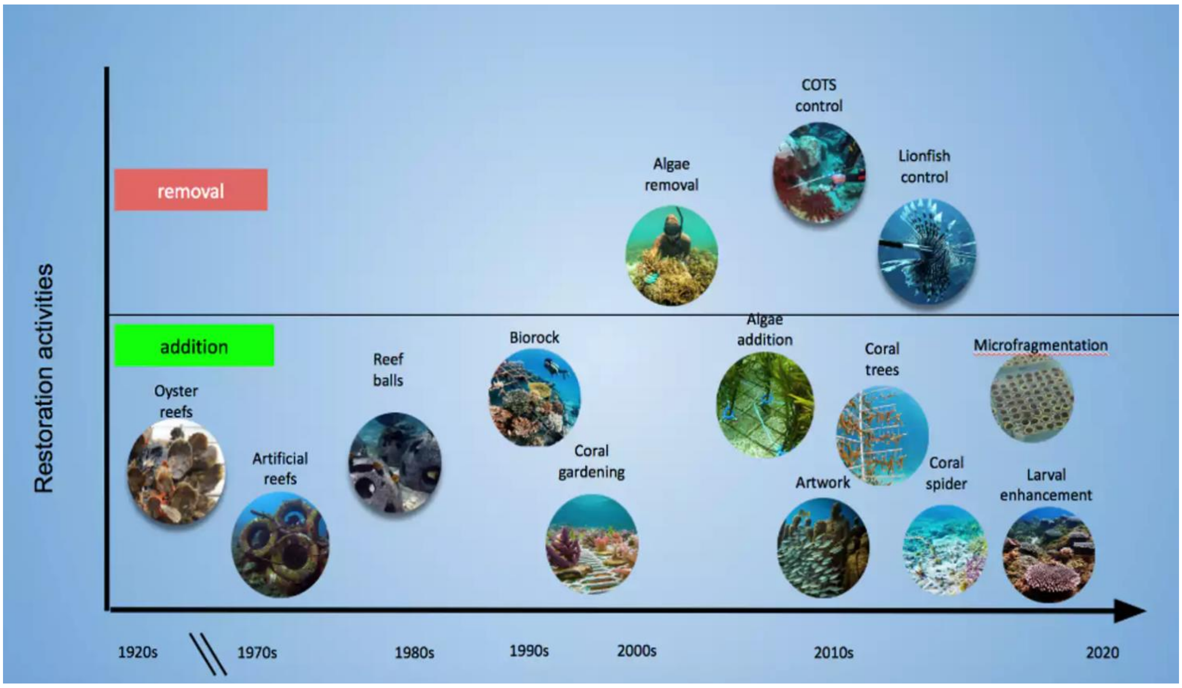


Figure 5-1 Introduction of reef restoration approaches over time (source: Smith & McLeod 2018)

5.1.1 Physical Restoration/Substrate Stabilisation

Physical restoration can be defined as the process of repairing reef structures and enhancing the condition of the substrate to encourage natural recovery (Edwards, 2010).The process of physical restoration involves the stabilisation, rebuilding and enhancement of a reef site, including methods such as the removal and stabilisation of large fields of rubble (Mickelfield, 2018). Rationale for physical restoration is often sourced in the use of “emergency reef triage” whereby, following a significant disturbance event, emergency triage can significantly impact, and improve, the recovery of the reef in the short-term (Edwards & Gomez, 2007). Such actions may involve cementing or epoxying large cracks in the reef framework, righting/reattaching corals, sponges and other reef organisms. Physical recovery methods can be useful for the stabilisation of larger pieces via epoxy, or in low-energy environments.

The removal of rubble is said to prevent injury, while facilitating the preservation of large pieces of live coral (Precht, 2006). The removal of larger quantities of rubble requires the use of a barge with suction, guided by underwater divers, whereas smaller quantities can be removed by divers using baskets or lift bags (Precht, 2006). Where large areas require restoration, stabilisation may be a more viable method of reducing potential damage. Edwards (2010) illustrates that there are three main methods of substrate stabilisation– netting, rock piles and concrete slabs (Edwards 2010). To expand, rubble can be stabilised in place using adhesive materials such as epoxy or overlay structures such as limestone boulders or concrete mats (Precht, 2006).

Alternatively, recent feasibility trials (BMT 2019) suggest a superior approach to stabilisation coral rubble (and subsequently enhancing coral recruitment and growth), is to use natural fibre net bags to accumulate rubble piles in a manner that both promotes rubble consolidation (stabilisation) and re-established a more complex physical reef structure (e.g. reef height, rugosity, topography etc.). Such an approach provides immediate structural habitat benefits to non-coral biota (e.g. fish), provides wave attenuation for coastal protection and habitat refugia, and provides a natural substrate for facilitating coral recruitment.

Limestone boulders can be designed and stacked to recreate the look of and replace the destroyed reef. Plastic composite rebar can be placed in the concrete for improved attachment between boulder and concrete layers. Furthermore, they can provide an effective and comparatively low-cost method of restoring the stability to rubble fields in less exposed locations and environments (Edwards & Gomez, 2007). These boulders can be barged to the site and lowered to the rubble field with a crane. Organised in piles or in a layer covering the area, the goal of the structure is to stabilise the rubble surface and reduce movement (Jaap, 2000). The boulders provide 3-D structural replacement, and gaps between them provide refuge sites for mobile fauna (Jaap, 2000). Additionally, the boulders enhance the opportunities for benthic recolonisation and recruit algae, sponges, octocorals, and stony corals (Precht, 2006).

Other stabilisation efforts involve using flexible concrete mats or pouring concrete onto the unstable rubble (Mickelfield, 2018). Much of the focus surrounding substrate stabilisation has involved the laying of artificial material on top, or attaching it to, the reef substrate (Rinkevich, 2005). This structure is referred to as a stabilisation mat and are used as a method of physical recovery to increase the stability of a reef area. The designs of stabilisation mats vary, cement and concrete tiles (connected by rope or cables, and often reinforced by steel) that form a mat structure are the most common materials used, although they can also be made out of plastic or natural rock (Mickelfield, 2018) (Rinkevich, 2005). However, Jaap (2000) does not recommend the use of stabilisation mats in locations with strong currents and wave surges. Furthermore suggesting that physical recovery and stabilisation efforts in high-energy environments can be expensive and, in some cases, ineffective. Some claim that the action of lashing corals to the seabed to form a grid (as another method of substrate stabilisation) is equally as successful, but cheaper and involves less labour (Rinkevich, 2005).

Physical restoration has been the traditional focus of coral reef restoration. However, coral community development often requires a significant amount of time to form a functioning coral ecosystem even after the physical environment has been restored (Precht, 2006). This had led to increased interest in alternative coral restoration methods, such as transplantation.

Figure 5-2 Examples of substrate stabilisation approaches for coral rubble (sourced from: Raymundo et al. 2007 (left), Precht 2006 (middle), NOAA 2019 (right))

5.1.2 Artificial Reefs (ARs)

Artificial Reefs (ARs) can be defined as structures constructed or placed at sea to improve and rehabilitate coastal systems (Pickering, 1996). The shape, size, form and material of an AR can vary widely depending on the application, budget and objectives. Early ARs developed consisted of readily available materials including stone, rock and timber, however concrete and steel are now the most common AR material. Pre-constructed items including offshore platforms, shipwrecks, breakwaters, tires and plastics are also being used as ARs (Lee, et al., 2016). Currently, ARs are being constructed and deployed for a range of different applications including coral restoration, biodiversity preservation, improve fishery production and management, habitat restoration and for sporting purposes (e.g. diving, recreational fishing, tourism) (Lee, et al., 2018).

A marked increase in AR research has occurred over the past 5 years, reflecting an increased demand for ARs. The majority of papers and projects have been published or undertaken in the USA and Japan, however a recent increase has been seen in Australia, Brazil, Korea and China, implying that these countries are actively implementing AR projects (Lee, et al., 2018). ARs are seen to be a popular method for coral and habitat restoration as they have been widely implemented and can be designed and created with a simple scientific input (i.e. compared to larval restoration, coral gardening, transplantation). ARs can also be defined as a product compared to the coral restoration methods, which has led to their commercialisation by companies such as ReefBall.

As described above, ARs is a collective term, however more specifically the use of ARs as coral restoration methods are commonly either pre-cast concrete modules or steel frames, or a combination of both. However, ARs for coral restoration are not exclusively made out of these materials. Current research for ARs have largely focussed on linking the success of the trial (coral recruitment, mortality, growth) to physical variables of the AR including size, shape, complexity, composition and void space (structural complexity). The composition and structural complexity of ARs is significant to the longevity and success of coral restoration (Al-Horani & Khalaf, 2013). However, due to the wide variety of variables considered in the design and construction, a scientific consensus on the most effective ARs is not readily concluded from the literature. Increased research into experimental materials for the ideal composition of ARs is adding increased variability. Furthermore, studies are not always focussing on the effect of AR structures to the surrounding environmental (e.g. leaching of chemicals/nutrients into the water).

Rinkevich (2005) found from a review of AR literature that it is questionable whether results obtained from one restoration site can be extrapolated to another, due to varying results regarding coral recruitment, mortality and growth in relation to specific in-situ environmental factors. However, several studies lend to positive reinforcement for the use of ARs as coral restoration methods which shows ARs (of varying types) can provide high rates of survivorship, enable natural recruitment and reproduction of corals, have minimal impact on seawater (when studied), provide a foundation for larval seeding, enable high biodiversity and provide a successful recruitment environment for fish assemblages (Sherman, et al., 2002; Suzuki, et al., 2011; Al-Horani & Khalaf, 2013; Yusof, et al., 2015; Ng, et al., 2017; Pennesi & Danovaro, 2017).

The application of ARs is variable dependent on the scale of the project and the structural complexity of the AR. For ARs in the form of pre-cast concrete, or concrete like material require detailed planning, can be labour and material intensive and require expensive logistics. For bulkier heavier ARS units, large vessels with cranes are required for deployment. Some AR designs can be constructed underwater or deployed by hand for example those built from steel reinforcement. The intensive and expensive planning and deployment of ARs can be offset by relatively easy and inexpensive management because of natural recruitment and reproduction of corals. Long term monitoring is however a key requirement to understand the efficacy of ARs.

Figure 5-3 Examples of artificial reefs constructed for the purposes of reef restoration ((sourced from: Eternal Reefs 2018 (left), Suzuki et al. 2011 (bottom right), Global Coral Reef Alliance 2018 (top right))

5.1.3 Coral Gardening, Transplantation and Microfragmentation

The concept of coral gardening is like that of forest restoration whereby stock is grown in nurseries and then transplanted into areas that require planting. For coral gardening this process can include gathering isolated ramets, nubbins and spats and cultivating these in *in-situ* protected underwater nurseries or in *ex-situ* land-based nurseries before being transplanted to the required location (Rinkevich, 2005).

The style of ex site nursery is typically similar (e.g. regulated tank/pond set up) however in-situ nurseries can vary widely between mid-water (rope lines/stakes), natural (shells/rocks) and artificial (steel frames/concrete) benthic based structures. Harvesting of donor stock for the nurseries can occur from attached corals or non-attached corals from pre-disturbed areas, or from pre-exiting nurseries. A popular ex-situ approach is the collection settlement, and maintenance of planula-larvae and spats under optimal conditions (Rinkevich, 2005). Transplanting methodologies can vary based on the complexity, budget and in-ex-situ nature, however will typically occur pre-attachment works and conditioning of the substrate/required location (e.g. grinding/scraping/brushing), preparation of coral fragments (e.g. stabilisation with toothpicks/attachment to small disc) and attachment (gluing/tying).

The concept of coral gardening can provide support coral reef communities and provide a tool for coral restoration. The concept is not widely studied as Artificial Reefs (ARs) however studies have shown that coral gardening and transplantation can obtain high survivorship post transplantation in the short term (Rinkevich, 2014). Much of the literature on coral gardening focusses on the secondary benefits gained from the nursery concept or the initial success of attachment post transplantation, however key indicators such as growth and survivorship long term are not well studied (Rinkevich, 2014). The secondary benefits from coral gardening activities include increased genetic variability and repositories, reduction of coral mortality during damaging events, provision of active supplies for management and reduction of collection of coral colonies from the wild (Epstein, et al., 2003; Rinkevich, 2005; Rinkevich, 2014). Mid water floating nurseries can also provide significant secondary benefits including enhanced oxygen and food for marina fauna due to swinging action, self-cleaning of sediment (Rinkevich, 2014). It is estimated that one coral colony can be produced from between $US 0.17 and 0.19 (Rinkevich, 2014).

Gardening and transplantation have scientific challenges regarding the design and planning of activities including genetics, species combinations, landscape manipulations, biological engineering and key species selection (Rinkevich, 2005; Rinkevich, 2014). It has also yet to be proven a large ecologically significant scale (Rinkevich, 2014). The requirement of harvesting for transplantation can disturb healthy reefs and inflict stress on donor colonies, as well as being costly when large quantities are relocated from a donor area directly into the damaged site (Epstein, et al., 2003). Direct transplantation also leaves aspects of transplant survivorship and growth dependent on reef conditions at the damaged site which can be risky as survivorship of corals that are transplanted directly upon harvest into a damaged site is often low (Epstein, et al., 2003). Transplantation of coral fragments to unstable environments such as to rubble has proven to be have limited effectiveness (Rinkevich, 2005).

However, fragments have the potential to survive, reattach and reproduce if conditions are favourable (Smith & Hughes, 1999). Smith and Hughes (1999) theorise that the survivorship for fragments may be high enough to promote the small-scale recovery of degraded reefs, if artificially generated fragments are successfully seeded into degraded reefs. Fragmentation has the potential long-term advantage of reducing risk- as the risk of mortality is spread over multiple fragments.

Micro-fragmentation, as a means to stimulate coral growth, is currently being used as a method of coral reef restoration and recovery. Micro-fragments are small (~1 cm^2) fragments of coral, as opposed to larger fragments that can range in size from 16-64 cm^2, which can be planted/propagated in disturbed reefs (Page, et al., 2018). Propagation via micro-fragmentation represents a potentially renewable source for coral reef restoration projects (Page, et al., 2018). A study by Page et al. (2018) has determined that, given favourable locality and minimal predation, the rate of production/tissue generated by micro-fragmentation can greatly exceed that of larger fragments. However, in the study conducted by Okubo et al. (2007), it was suggested that there is a trade-off between reproduction rate and survival, with smaller fragments exhibiting a lower survival rate than larger fragments. Results of the effectiveness of micro-fragmentation versus fragmentation vary depending on species and other factors used in each study, there appears to be no conclusive decision on the success of this method or its long-term viability.

Figure 5-4 Examples of coral gardening for transplantation (sourced from: (Coral Vita 2018 (left), Diveplanit 2018 (bottom right), Leal, et al. 2013 (top right))

5.1.4 Larval Restoration

Larval restoration is a modern coral restoration method which is currently being studied by several universities and research organisations including James Cook University (JCU), Queensland University of Technology (QUT), Southern Cross University (SCU) and The Nature Conservancy with SECORE. The concept involves capturing naturally spawned eggs, developing them in laboratory or *in-situ*, to larvae and then releasing them (settlement) in areas requiring restoration. Millions of sexually derived larvae of wide genotypic diversity can be cultured during the process. Most of work has been conducted in Australia, the Caribbean and the Philippines however, limited published literature is available due to the novelty of the method. Published studies include those by Heyward et al. (2002), Edwards (2015) and De la Cruz & Harrison (2017).

Results from restoration studies have indicated that mass larval supply can enhance rates of settlement onto badly degraded areas and significantly increase coral recruitment (De la Cruz & Harrison, 2017). De la Cruz & Harrison (2017) implemented *ex-situ* culturing of larvae and settlement on tiles cut from dead Acropora found that survivorship and growth of coral recruits occurred within the short term with most colonies growing rapidly and spawned successfully after 3 years. The Nature Conservancy (with SECORE) have also witnessed previously out planted corals from larval restoration activities reproducing naturally on their own (The Nature Conservancy, 2018). Previous studies undertaken by Heyward et al. (2002) and Edwards (2015) both studied areas adjacent to healthy coral communities, in protected areas, which showed less promising results than that of De la Cruz & Harrison (2017). Heyward et al. (2002) implemented *in-situ* culturing of larvae from coral spawn slicks and seeding on terracotta tiles and found that settlement rates on seeded areas were

100-fold less than control (natural recruitment sites) sites. Edwards (2015) implemented *ex-situ* culturing of larvae and seeding on concrete pallet balls and found no significant differences between seeded and control sites.

Larval restoration has gained recent popularity from universities and research organisations as it provides several benefits not obtained from traditional coral restoration methods including artificial reefs and asexual fragmentation of adult colonies in combination with nursery and transplantation technique (De la Cruz & Harrison, 2017). These methods are labour intensive, sometimes expensive and studies which rely on coral fragmentation can increase disease risk at the donor site and damage donor colonies as well as using fragments with limited genetic diversity (De la Cruz & Harrison, 2017). Larval restoration can be significantly affected by post-settlement mortality, particularly regarding chronic disturbances and key threats such as poor water quality, competition with other reef invertebrates, overgrowth and predation (De la Cruz & Harrison, 2017).

Larval restoration also has a significant potential for up-scaling restoration efforts for larger reef restoration projects and can be undertaken relatively inexpensive. De la Cruz & Harrison (2017) estimated an average cost of $US 20.94 for each colony survivor the 35 month trial, which bodes well against land based nurseries which can cost up to $US 325 for coral colonies, and sits competitively against coral transplantation which can cost $13 per coral colony (De la Cruz & Harrison, 2017).

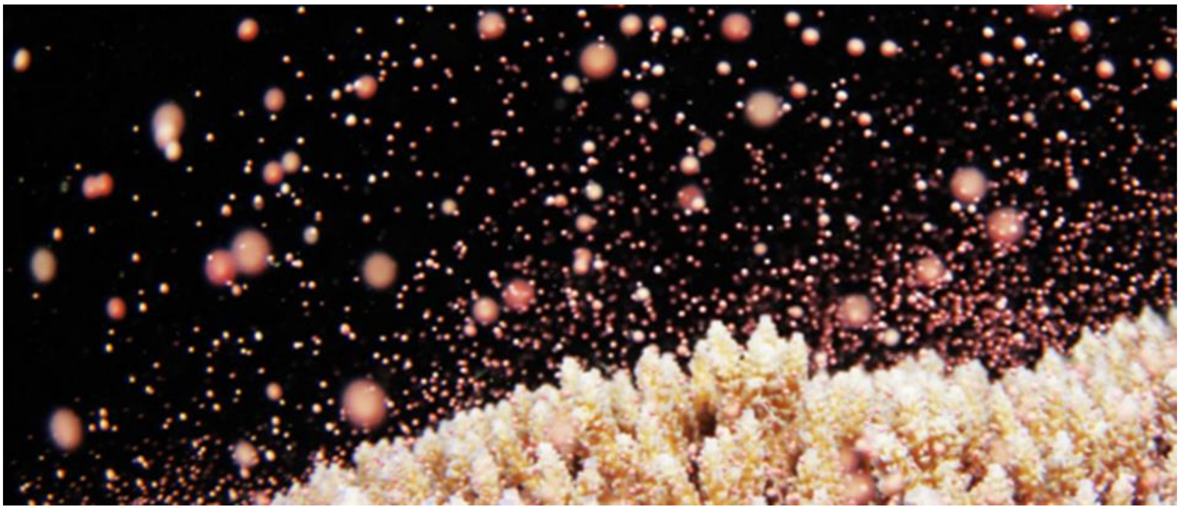


Figure 5-5 Coral spawning (sourced from: TUDelft 2018)

5.1.5 Management of External Impacts to Benefit Natural Recruitment (Indirect Restoration)

Coral reefs face a variety of stressors that can reduce and inhibit survival and resilience to disturbance events. Edwards (2010) has highlighted that in combination with other reef restoration and restoration techniques, effective management and intervention of such stressors can improve ecosystem recovery. A key principle in ecological restoration is to re-establish self-sustaining and resilient ecosystems (Maya, et al., 2016). Within coral reef restoration, long-term sustainability relies on enhancement of coral recruitment- where methods such as transplantation provides an additional source of recruits (Maya, et al., 2016). Effective management however can help to minimise the exposure and severity of threats to coral reefs to, in turn, benefit natural recruitment (Chavanich, et al., 2015).

Some of the threats (both anthropogenic and natural) that inhibit resilience and recovery include; pollution release, overfishing, coastal development, introduction of non-indigenous species, climate change and ocean acidification (Chavanich, et al., 2015).

The Crown-of-thorns starfish (CoTS) preys on the polyps of reef-building corals and, during population outbreaks, can fundamentally alter reefs and their biological communities (McCook, et al., 2007). For the Great Barrier Reef, CoTS have been associated with the widespread loss of hard coral cover on reefs during periodic outbreaks across their entire range (McCook, et al., 2007). Westcott et al. (2016) outlines that the mitigation of CoTS is highly important for management and coral recovery, as it can be undertaken on individual reefs and reduce the cumulative stresses experienced by the reef that can inhibit natural recruitment.

Macroalgae removal is a practice that reduces competitive pressures from algae to coral. This is of particular relevance in Seychelles where many reefs have become algae dominated, and should be considered for suitable sites, either in isolation or to complement other restoration activities.

Resilience is also eroded by chronic human impacts that cause persistent elevated rates of mortality and reduced recruitment of larva (Hughes, et al., 2003). The management of such activities, such as nutrient run-off, can have multiple impacts for natural recruitment. For example, a study done in Hong Kong found that excess pollutants and nutrients was directly linked to low coral recruitment and fewer zooxanthellate octocorals (Fabricius, 2005). Furthermore, CoTS larvae are suggested to be supported by the enhancement of phytoplankton associated with high nutrient levels in terrestrial runoff (particularly associated with flood plumes) (McCook, et al., 2007). Thus, illustrating that this stressor, if unmanaged or ineffectively managed, can inhibit the resilience and recovery of coral following disturbance events.

The management of the stressors that impact the resilience of coral and prevents their recovery in the face of disturbance events can be classified as indirect restoration. By focusing on restoring the physical and chemical environmental conditions, the degree to which these stressors can inhibit natural recruitment (and thus restoration) may be significantly reduced depending on management effectiveness.

5.2 Key Reef Restoration Projects in the Seychelles To Date

Key examples of existing coral reef restoration works in the Seychelles are summarised in the following tables (Table 5-1 to Table 5-8). The most common approach has been around the combined coral nurseries, gardening and transplanting concept. There has also been some interest in next generation seeding technology.

Table 5-1 Coral transplantation at Cousin Island Special Reserve

Aspect	Details
Reference	Maya, P., Smit, K., Burt, A. & Frias-Torres, S., 2016. Large-scale coral reef restoration could assist natural recovery in Seychelles, Indian Ocean. Nature Conservation, Volume 16, pp. 1-17. Available at: https://natureconservation.pensoft.net/article/8604/list/4/

Aspect	Details
Aim of Study	To quantify how coral transplantation influenced natural coral recruitment at a large-scale coral reef restoration site in Seychelles, Indian Ocean
Location	- Transplanted at a no-take marine reserve of Cousin Island Special Reserve. - Continuous fringing reef on the south-west side of Cousin Island. The reef is approximately 400m long and 30 m wide (ca. 1.2 ha), ranging in depth between 6.5 and 13 m.
Techniques/Method	Between November 2011-June 2014, a total of 24,431 nursery-grown coral colonies from 10 different coral species were transplanted in 5,225 m2 (0.52 ha) of degraded reef to assist in natural reef recovery. - Deployed settlement tiles onto the reef between 9th and 15th January 2014, over 14 months after first coral transplantation. - Coral recruitment (spat <1 cm) was compared among all three study sites over a six-month period using settlement tiles. - Two ceramic tiles (16 × 16 × 0.8 cm) were placed separately on a concrete block and secured with a plastic cable tie.
Implementing Parties	- Study conducted by academics from: Nature Seychelles, Nelson Mandela Metropolitan University (NMMU), Seychelles Islands Foundation, Smithsonian Marine Station - Funding to Nature Seychelles was received through the United States Agency for International Development (USAID) Reef Rescuers Project
Outcomes	- Results deemed consistent with alternative studies - approach confirmed the hypothesis that scleractinian coral recruitment and juveniles will be higher at the transplanted site than at the degraded site. - Six months after tile deployment, total spat density at the transplanted site was 1.8 times higher than the healthy site and 1.6 higher than the degraded site - Study issue: healthy-degraded-transplanted site cluster lacks replication at multiple locations and multiple times which limits the generalization of results
Lessons learned / Recommendations	- Recommend future research use techniques to identify immigrant and locally produced spat (e.g. assignment tests) to determine the real effect coral transplants have in local seeding or larval attraction from elsewhere. - Physical (varying sizes/growth forms of coral transplants on sites) and biological (e.g any reef organism known to help coral recruit survival) complexity should be promoted in reef restoration projects to enhance the survival of settlers - In addition, in future studies it would be valuable to include a measure of complexity (e.g. rugosity) to evaluate coral settlement and recruitment on transplanted sites with varying levels of structural complexity. - Increasing the size of the transplanted area and expanding the monitoring time are required to observe any positive effects of active reef restoration

Table 5-2 Coral gardening at Cousin Island Special Reserve

Aspect	Details
Reference	Frias-Torres, S., P.H. Montoya-Maya, N. Shah (Eds). 2018. Coral Reef Restoration Toolkit: A Field-Oriented Guide Developed in the Seychelles Islands. Nature Seychelles, Mahe, Republic of Seychelles. Available at: http://natureseychelles.org/knowledge-centre/scientific-papers-database/scientific-papers/273-coral-reef-restoration-toolkit-a-field-oriented-guide-developed-in-the-seychelles-islands/file
Aim of Study	Purpose of this Toolkit is to describe how to complete a coral reef restoration project, using the 'coral gardening' concept. We provide guidance on appropriate design, logistics, and execution of the project based on our own experience using field-tested methods (developed by Nature Seychelles or others) in the Republic of Seychelles, Western Indian Ocean (WIO). Information used in the toolkit sourced from a 2014 study - outlined below
Location	- Within the marine protected area of the Cousin Island Special Reserve, at a degraded reef site.
Techniques/Method	- Coral gardening was the core technique/method/concept used (two step protocol) 1) Generated a pool of farmed colonies in underwater nurseries until they reached a threshold transplantation size 2) The nursery colonies were then transplanted onto degraded reefs in the study area 12 midwater nurseries (nine rope nurseries and three net nurseries) were built and cultivated and initially filled with (up to) 40,000 coral fragments/nubbins of 34 branching, massive and encrusting coral species.
Implementing Parties	- Production of the Toolkit was funded by the United States Agency for International Development (USAID) though the Nature Seychelles' Reef Rescuers Project 674-A-00-10-00123-00 and produced by Nature Seychelles – local not-for-profit - The study that the toolkit is based on was completed by Reef Rescuers and was partially supported by the United National Development Program (UNDP) and the Global Environment Fund (GEF) Tourism Partnership Programme.
Outcomes	- The success of the project is not yet determined. - However, if the "toolkit" is followed, the results are hypothesised that: o Scleractinian coral settlement and recruitment rates will be highest at a healthy site and lowest at a degraded site, with a transplanted site showing settlement and recruitment rates higher than the degraded site but lower than the healthy site. - For the study that the toolkit is based on: o Total of 24,431 corals were transplanted in an area of the 5,225 m^2 within the no-take marine reserve of Cousin Island Specieal Reserve o Part of the report was funded by the UNDP and GEF Tourism Partnership Programme, whereby from this contribution it has been estimated that approximately 2,015 corals have been

Aspect	Details
	transplanted in an area of 1,636 m^2 at Petite Anse Kerlain (within the Constance Lemuria resort on Praslin).
Lessons learned / Recommendations	N/A

Table 5-3 Investigating coral recruitment at inner islands

Aspect	Details
Reference	Chong-Seng, K.M., Graham, N.A, & Pratchett, M.S. (2014). Bottlenecks to coral recovery in the Seychelles. Coral Reef, Volume 33. 449-461. Retrieved 9/01/2019, Available at: https://link-springer-com.ezproxy.library.uq.edu.au/content/pdf/10.1007%2Fs00338-014-1137-2.pdf
Aim of Study	To investigate spatial variation in local abundance of scleractinian corals in the Seychelles at three distinct life history stages (recruits, juveniles, and adults) on reefs with differing benthic conditions. This study identified bottlenecks to recovery of coral assemblages that varied depending on post-disturbance habitat condition.
Location	Inner Islands, Seychelles - the inner islands rise from the Mahé Plateau (20–70 m depth) and are predominantly granitic with well-developed carbonate fringing reefs
Techniques/Method	Looking at a variety of methods to look at coral recruitment; o Nine sites in total, three for each benthic condition chosen o To assess spatial variation in settlement among reefs in different conditions, 10 clay tiles (11x 11x1 cm), unglazed on the base, were attached to half concrete construction blocks using stainless steel bolts and spacers. o Tiles were haphazardly placed onto each reef within an area of approximately 125 m^2, with adjacent tiles separated by a minimum of 1 m. After 3 months, all tiles were collected, bleached, sun-dried and the underside examined for coral recruits using a dissecting microscope.
Implementing Parties	- Funded by the Australian Research Council, a Western Indian Ocean Marine Science Association Marine Research Grant, and the Seychelles Fishing Authority through the Seychelles/European Union Fisheries Partnership Agreement. - Study completed by academics from Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University.
Outcomes	- Study indicates that there are demographic bottlenecks affecting the recovery of the inner Seychelles' coral assemblages - bottlenecks appear to vary among reefs depending on their post-disturbance habitat condition. - High cover of macroalgae may prevent the recruitment of or inhibit subsequent growth and survival of newly settled corals, there appears to be strong settlement and survival to juvenile stages in areas of unconsolidated reef rubble.

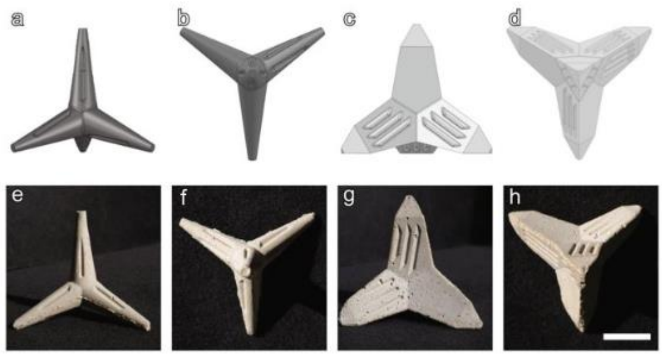
Aspect	Details
	- Corals settling on rubble-dominated reefs do not appear to be surviving to become adults - periodic hydrodynamic disturbances and turnover of accumulated rubble may be the reason. - Importantly, limitations to coral recovery and required management actions vary depending on habitat condition.
Lessons learned / Recommendations	- Temporal studies are required to fully elucidate incoming recruitment patterns in the Seychelles - Important to qualify the study by saying that limitations to coral recovery and required management actions vary depending on habitat condition - Further study will be necessary to try to understand why macroalgae is proliferating only on certain reefs in the Seychelles o Management interventions that improve corals as competitors could promote recovery, for example, active removal of macroalgae following storm damage or periods of seasonal senescence.

Table 5-4 Coral gardening and transplantation at Cousin and Praslin Islands

Aspect	Details
Reference	USAID. (2017). Restoring Coral Reefs in the Face of Climate Change in the Seychelles. Washington DC: U.S. Agency for International Development.
Aim of Study	Restoring damaged coral reefs in the Seychelles to increase their resilience and reduce the vulnerability of coastal communities to storms, floods and sea level rise.
Location	- Coral reefs around Cousin and Praslin islands.
Techniques/Method	Small fragments of coral from healthy sites are grown in coral gardens. Once they are larger, the fragments are transplanted onto damaged reefs.
Implementing Parties	- Project donors include: United States Agency for International Development (USAID), Global Environment Facility (GEF) and the United Nations Development Programme (UNDP) - Total funding: $1,014,000 (from 2006-2011, but project has been extended until 2019).
Outcomes	- Report claimed success, key findings include: o 12 mid-water nurseries built and cultivated with ~40,000 coral fragments from 32 species o 11,000 coral colonies transplanted onto degraded sites o 5,225 m^2 of coral reef transplanted with cultivated coral colonies o ~700% increase in coral cover in transplanted sites, up from about 2 percent in 2012 to 16 percent by end of 2014 - The long-term “success” of this mass transplantation is yet to be monitored but the project has already had a very positive knowledge-building impact.
Lessons learned / Recommendations	- Not all coral reef transplantation projects enhance the resilience of coastal communities and marine ecosystems to climate stressors.

Aspect	Details
	- This project features several innovative approaches that are important to their combined effectiveness as a climate change adaptation strategy: o Work at a meaningful scale: This project transplanted reefs at a large, ecologically meaningful scale (~5,200 m^2 transplantation area) to recover important ecosystems services such as coastal protection. o Design pilots to minimize outside threats: The project sites were chosen to minimize risks from other threats to coral reefs that interfere with coral recovery, such as overfishing and pollution. o Maximize opportunity for resilience: The project tested the hypothesis that transplanting coral fragments that displayed resilience to the 1998 El Niño-related bleaching event will improve the resilience of the transplanted area. o Allow adequate time for assessment and validation: The project invested considerable resources to monitor the effectiveness of the transplantation process on reef resilience and requested an extension to assess the impacts of a 2014-2016 regional bleaching event on the transplanted sites.

Table 5-5 Trial development of coral seeding units

Aspect	Details
Reference	https://africatimes.com/2018/01/04/for-nations-like-seychelles-new-coral-restoration-technique-may-boost-success/ Chamberland, V. r. F., D. Petersen, et al. "New Seeding Approach Reduces Costs and Time to Outplant Sexually Propagated Corals for Reef Restoration." Scientific Reports 7(1): 18076. Available at: https://www.nature.com/articles/s41598-017-17555-z#Abs1
Aim of Study	To explore new and alternative means to coral reef restoration for maximum impact and minimum time required **Not in Seychelles but future plans for implementation**
Location	**Not in Seychelles yet but future plans for implementation**
Techniques/Method	SECORE developed a method of growing coral larvae in "seeding units," that don't have to be manually attached one by one. They self-stabilize and just need to be wedged in crevices (tips of the pods narrowed toward their ends to increase the probability that they would get stuck in crevices and thus increase overall attachment success).  Tetrapod-shaped substrates for coral larval settlement. Computer-aided-designs (CADs) for Type I: (**a**) side view and (**b**) top view, and for Type II: (**c**) side view and (**d**) top view. Tetrapods before they were conditioned in a flow-through aquarium system: Type I: (**e**) Side view, and (**f**) top view, Type II: (**g**) side view, and (**h**) top view. Scale bar = 3 cm. CADs by Kempten University of Applied Sciences and photos by DP.
Implementing Parties	- Funded by SECORE International through donations and grants of TUI Cruises, the Green Foundation, the Clyde and Connie Woodburn Foundation, Futouris e.V., the Montei Foundation, and one anonymous funder.
Outcomes	- By avoiding the need for outplanting corals using binding materials, the seeding approach allows the deployment of large numbers of young corals in a very short amount of time and at low cost - The technique was studied in Curaçao, where the new coral's survival rate met the target level after one year. - This technique was most effective in reefs with moderate to high topographic complexity, where tetrapods rapidly became stabilized within the reef framework and resulted in a high SU (seeding unit) yield relative to traditional outplanting methods - If the new sowing approach is combined with more effective coral larvae rearing techniques, costs of reef restoration could become comparable to the costs of existing mangrove and salt marsh restoration efforts.

Aspect	Details
Lessons learned / Recommendations	- Improvements can still be made in future tetrapod designs to optimize the survival and growth of coral settlers

Table 5-6 Coral nursery and transplantation at Félicité Island

Aspect	Details
Reference	Zil Pasyon Six Senses. (2018, November 8). Six Senses Zil Pasyon Transplants First Corals from Its Coral Nursery. Retrieved from Six Senses: https://www.sixsenses.com/six-senses-zil-pasyon-transplants-first-corals-from-its-coral-nursery
Aim of Study	Aims to restore a seafloor area of about 6,500 square feet (600 square meters) via coral transplantation from coral nursery.
Location	- Félicité Island, Seychelles
Techniques/Method	- Project began with the collection of healthy corals from threatened reefs nearby Félicité and the creation of a coral nursery, just off the shore of Anse Peniche, the northernmost beach of the resort. The team is growing corals and using those to replant a reef. - 1,800 coral fragments were harvested (suitable fragments were identified by qualified marine biologists). Donor corals were chosen from colonies from neighboring Albatros Island, known to be vulnerable to sea snail infestation yet having simultaneously proven their strength and heat-resistance by surviving the 2016 mass bleaching event in the Indian Ocean. - The nursery, which allowed the corals to grow for one year, was constructed with ropes and pipes for buoyancy and resembled an underwater hammock about 65 by 20 feet (20 by six meters).
Implementing Parties	- Six Senses Zil Pasyon Resort in partnership with local NGOs Nature Seychelles, Ramos Marine and Island Reserve, in addition to the Seychelles National Park Authority (SNPA)
Outcomes	- 548 corals have been returned to the natural reef environment. - During the one-year period the study has been undertaken, corals grew over 200 percent on average, with a growth range of between 85 and 422 percent per harvested segment. - Survival rate was 93.4 percent, with the majority of the loss resulting from nursery damage that unfortunately took place during August's rough monsoon season.
Lessons learned / Recommendations	- 548 corals have been returned to the natural reef environment. - During the one-year period the study has been undertaken, corals grew over 200 percent on average, with a growth range of between 85 and 422 percent per harvested segment. - Survival rate was 93.4 percent, with the majority of the loss resulting from nursery damage that unfortunately took place during August's rough monsoon season. Lessons learned/ recommendations - Daily maintenance was required, with the team monitoring growth and cleaning the delicate fragments with toothbrushes to remove algae and barnacles. - Challenges faced include;

Aspect	Details
	o Turbulent waters o Poor visibility + strong currents o Unexpected predation o Cold waters that ameliorate algae and barnacle growth (making cleaning more difficult)

Table 5-7 Nursery and transplantation initiative at Four Seasons Resort (Petite Anse Bay)

Aspect	Details
Reference	Lawrence, D. (2017, September 17). four projects in Seychelles to help coral reefs survive. Retrieved 01 10, 2019, from Seychelles News Agency: www.fourseasonsreefaction.com www.wiseoceans.com
Aim of Study	Restoring 10,000 square metres of coral reef
Location	- Petite Anse Bay
Techniques/Method	- The Project aims to restore 10,000 m^2 of degraded limestone reef, to increase the health of Petite Anse marine environment, increasing coral cover lost through the 1998 and subsequent coral bleaching events. - Concurrently the Project aims to increase awareness of and connection to coral reefs and the threats they face. - Following the coral gardening technique, the Project utilises asexual fragging and in-situ coral nurseries. Corals of Opportunity are the primary source of frags. after a 6-9-month nursery phase corals are transplanted onto bare natural reef substrate. - The Project uses two in-situ coral nurseries (shallow and deep) made of simple rebar arches, with capacity for 1500 corals and contains an average of 11 coral genera. - The nursery design was developed to provide simple cost-effective structures than can withstand the high-energy conditions experienced in the bay during the North West monsoon season. - Coral fragments are attached to small settlement bars which are hung from the rebar arches, allowing movement to reduce sediment build up and prevent fouling from settling organisms
Implementing Parties	- Managed and delivered by WiseOceans for Four Seasons Resort Seychelles, in collaboration with the Ministry of Environment, Energy and Climate Change.
Outcomes	- In 2018, on-site at Petite Anse alone, the Project engaged 1100 citizens in educational activities, workshops, events and sponsorships programmes.

Aspect	Details
	- Since the 2016 bleaching event the Project has seen a 95% survival rate across nursery and transplant stages. - The coral nurseries are situated close to the existing natural reef. Through this positioning we have found our nurseries benefit from herbivore algae grazing, becoming 'self-cleaning' which significantly reduces labour needed in the nursery.
Lessons learned / Recommendations	- The shallow nature of the bay (max 9m. Shallow nursery at 3-4 m, deep nursery at 8 m) has caused challenges to the Project, through the susceptibility of shallow waters to high temperatures and swell. The methodology used on the Project has been created to adapt to such conditions. - The Project initially utilised coral fragments which had shown resilience in the 1998 and 2010 bleaching events, however we found minimal resilience in these colonies to the 2016 bleaching event, during which the nursery suffered an 85% loss of frags. This loss was reflected in other RRP projects and natural coral reefs across the Seychelles inner Islands (which saw a 50% overall loss of corals on monitored reefs

Table 5-8 Coral nurseries Curieuse Marine Park & Praslin Island

Aspect	Details
Reference	https://www.icriforum.org/sites/default/files/ICRIGM31_MR_Seychelles.pdf
Aim of Study	To rehabilitate two coral reef sites around the island of Praslin which have been affected by climate-driven mass coral bleaching events that occurred between 1998 and 2014 and by doing so demonstrate viability of coral reef restoration.
Location	Curieuse Marine Park & Praslin Island Seychelles
Techniques/Method	- Building and managing coral nurseries utilising different techniques, and once solid media have been colonised attach these at designated restoration site (two sites).
Implementing Parties	- Project team embedded within Seychelles National Parks Authority - UNEP
Outcomes	
Lessons learned / Recommendations	- Bleaching is a risk to such projects. In this particular case, it caused significant loss in the coral nursery. - Without proper financial support either from externally or from associated money generating schemes, to cover costs of recovery after bleaching, it would be difficult for small entities to really implement such projects.

6 Ecological Potential and Risks of Coral Restoration in the Seychelles

There are a range of both opportunities and risks associated with any prospective coral restoration proposal, regardless of its scale or location. These must be considered on a case-by-case basis, while also taking into account larger scale (e.g. regional, national) interactions and trends.

We discuss here key drivers of reef condition and degradation in the Seychelles, which are critical to understanding the likelihood of success for a given restoration activity – if the underlying causes of reef degradation have not been addressed, then the chances of restoration failure increase. General risks associated with coral restoration are briefly outlined, noting that these would need to be factored into any prioritisation of potential restoration activities.

When then provide a separate description of the ecological potential and risks, specific to each key focus areas. These focus areas align with key 'Coastal Zone Management Units' identified in the draft Seychelles Coastal Management Plan 2019-2025, as introduced below. Note that the potential in this regard relates only to the ecological potential (i.e. based on bio-physical information) and does not yet take into account economic potential and other non-biophysical opportunities/risks. This provides a first-pass basis, which will be built upon during subsequent stages of this study.

6.1 Recent Coastal Zone Management Information

Our assessment intentionally complements/aligns with the outputs of recent extensive studies on coastal zone management in the Seychelles, as outlined below.

6.1.1 Coastal Zone Management Plan

The draft Coastal Management Plan (CMP) Seychelles (2019-2025) is an important information source which provides useful intelligence and information about the Seychelles Coastline and the approaches that are being considered to maintain and protect the coastal zone. The direction and guidance in the document will support the identification of where coral reef restoration is a likely management approach, and the types of outcomes that are desired from different coral restoration approaches.

We note that the CMP primarily focusses on the reduction of coastal flood risk and coastal erosion and does not identify areas where coral restoration may benefit other outcomes such as tourism. Such benefits will be identified through our study. The information from this report will be used to augment other information provided in the detailed site descriptions and prioritisation. The ecosystem services that can be delivered by reefs is a critical aspect for determining priorities for large scale restoration.

6.1.2 Coastal Zone Management Unit Summary Cards

The CZMU Summary Cards are site specific summaries and indicate where nature-based solutions such as coral restoration, or other near-shore interventions, can be of use. They are a vital supplement to the CZM Plan. The cards present a synopsis of relevant coastal hazards and processes, priorities for coastal management and current coastal management practices and interventions. This information will support consideration of drivers of reef condition, identification of historical coastal works that may have influenced site selection as well as other information that can be used to support prioritisation of coral restoration activities.

6.1.3 Deltares Mapping

The team has been provided with a series of mapping layers from work done by Deltares (2018). The mapping layers show the direction of wave runup and the wave runup reduction potential is reduced in reaching the coastal zone. These data will be used to develop a better understanding of the areas of influence of wave runup and where reef restoration may be implemented as a possible wave reduction mechanism. These data will be used as part of the consideration for prioritising coral restoration sites.

6.1.4 La Digue Shoreline Management Plan Studies

A Shoreline Management Plan and supporting technical information (e.g. bathymetry, benthic habitat data) was recently compiled for La Digue as part of the Seychelles Global Climate Change Alliance + (GCCA+) Climate Change Project (Artelia, 2018). In the context of La Digue, the plan notes that beaches are generally eroding, despite being mainly protected from waves by the reef. The plan appears to overestimate the health of the reef here, since our recent survey results suggest that the reef is already declining, which would exacerbate coastal erosion as a result of climate change.

The plan goes on to recommend actions for:

- Future monitoring (of coastal plateau);
- Mitigating risks of, and vulnerability to coastal erosion, marine submersion and saltwater intrusion; and
- Mitigating risks of, and vulnerability to, flooding on the coastal plateau.

If a variety of such actions were implemented together with a reef restoration/augmentation program, it is possible that positive reef health outcomes could be achieved.

It is noted that the abovementioned monitoring recommendations include Reef Check methodology for marine areas, which is applicable to the present coral restoration focus. Monitoring of actions from different projects should be aligned and streamlined as far as practicable.

6.2 Drivers of Reef Condition and Degradation in the Seychelles

6.2.1 Coral Bleaching Events

6.2.1.1 1997-1998 Bleaching Event

One of the largest and most severe bleaching events for the western Indian Ocean occurred in 1997-1998, during the extreme El Niño-related warm water event (Clifton, et al., 2012). This region suffered greatly, with an estimated mean live coral cover reduction from 27% to 3%, equating to an overall loss of up to 90% of live coral (Buckley, et al., 2008; Graham, et al., 2007).

The impact of this event on the Seychelles has varied widely depending on location and coral reef composition. In this region the bleaching event resulted in extensive losses of live coral habitat that has altered reef habitats on an unprecedented scale (Buckley, et al., 2008). The reefs of the inner

Seychelles (namely the shallow carbonate platform north of the Mascarene Ridge) was severely impacted, with coral mortality estimated at 70-95% (Harris et al., 2014). In the outer reefs of the southern Seychelles Islands, coral mortality has been estimated to range between 60-75%, with an estimated 60% loss of live coral cover (Buckley, et al., 2008).

Although not as extreme as other regions in the Seychelles, Aldabra Atoll and the neighbouring southern Seychelles islands of Assumption, Astove and St Pierre suffered coral cover losses of up to 50% - severely damaging the previously coral-rich ecosystem (Buckley, et al., 2008).

In addition to the gradual transformation of impacted reefs turning to rubble, rapid algal-colonisation was observed in some regions of the Seychelles in quick succession from this event, resulting in the weakening, or in some cases collapse, of the structural complexity of the reef (Frias-Torres, et al., 2018).

6.2.1.2 *2002 – 2003 Bleaching Events*

A barrier to the recovery of coral reefs in the Seychelles has been the continuing occurrence of bleaching events. After the 1998 bleaching event, progressive recovery of corals at most sites within the Seychelles was reflected (Abdulla & Obura, 2005). However, the bleaching events of 2002 and 2003 had non-uniform impacts on the recovery of carbonate and granitic reefs whereby, at some sites, the bleaching event killed high numbers of new coral recruits (Abdulla & Obura, 2005, Payet & Agricole, 2006).

In the inner Seychelles, post-2002 and 2003 bleaching events, slow growing corals (such as *Porites* and *Goniopora*) became increasingly dominant, suffering little from the bleaching events, encrusting and branching taxa however, reflected significant losses (Harris, Wilson, Graham, & Sheppard, 2014).

6.2.1.3 *2016 Bleaching Event*

The most recent major bleaching event occurred in 2016. Anecdotally, this event had a significant impact on the reefs, however little information has reached publication at this stage. Gudka et al. (2018) report this to be the strongest bleaching event in the region since 1998, and the inner islands were most severely impacted (i.e. 60% coral mortality as compared to 17% at outer islands).

Note that even, for major regional/global scale bleaching events, local effects in terms of coral responses are not necessarily consistent at smaller spatial scales. Figure 6-1 illustrates long term live coral cover data for selected sites across four Seychelles islands (data courtesy of Prof Nick Graham, Lancaster university). While there is a large gap in the monitoring data from 1994 to 2005, it suggests that corals at Cousin Island, and many carbonate reef sites elsewhere have shown negligible coral recovery since the 1997-98 bleaching event. In comparison, notable recovery (in terms of percentage coral cover) appears to be evident across much of Mahe in the 2005 to 2014 data. Coral cover was again consistently low (<12%) across all sites during the 2017 survey, following the 2016 bleaching event.

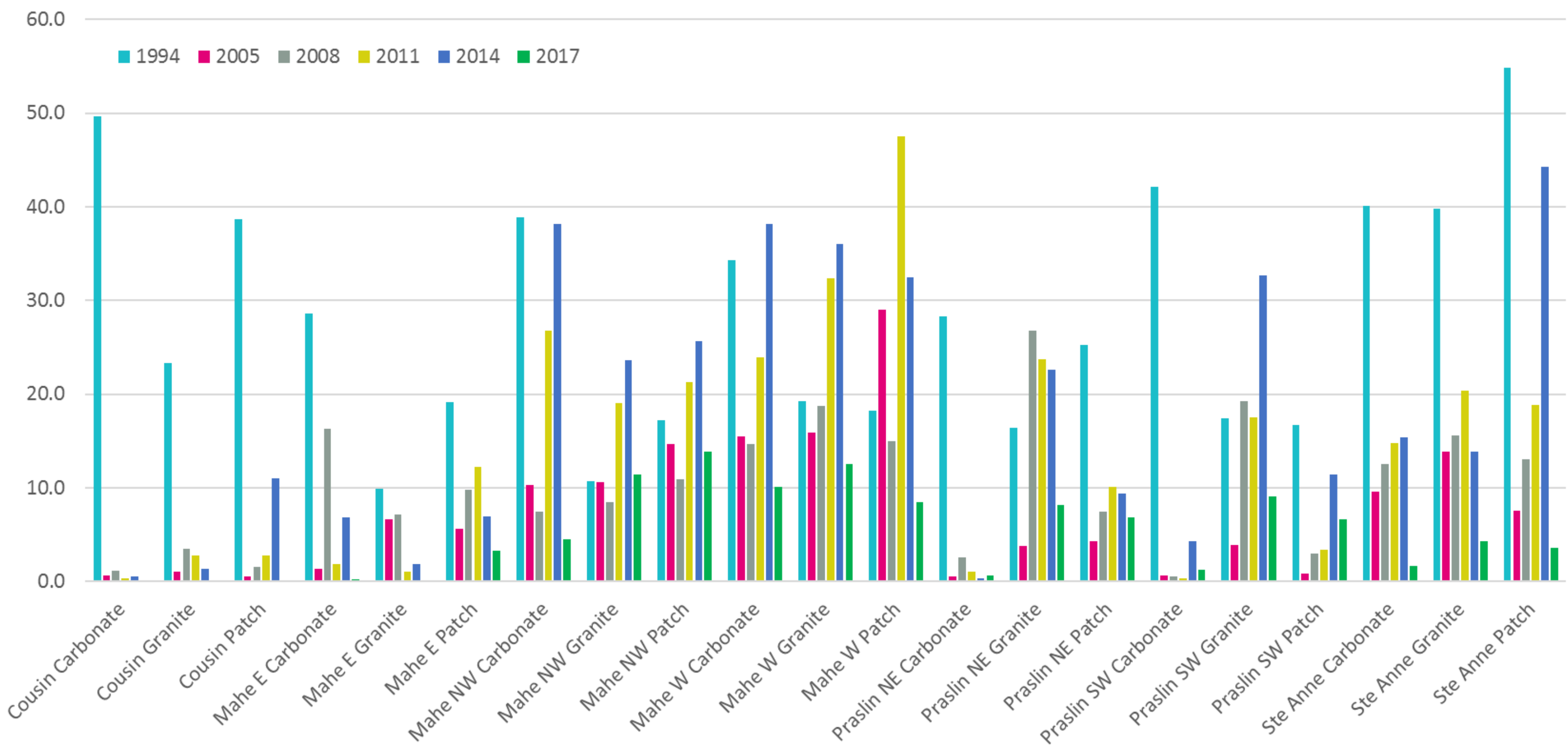


Figure 6-1 Trends in live coral cover at multiple sites in the Seychelles (data courtesy Nick Graham)

6.2.2 Tsunami/Storm Damage

On 26 December 2004, and continuing into the following day, the Seychelles were hit my multiple tsunami waves radiating from the Indian Ocean earthquake off the west coast of northern Sumatra. These waves had non-uniform impacts on coral reefs in the region. Abdulla & Obura (2005) indicate that although majority of the Seychelles suffered minimally, some sites were significantly impacted by the tsunami event. Reefs that were not in the direct path of the tsunami (such as majority of the reefs around the island of Mahé) were protected from the extent of the impact by nearby islands (for example, by the northern islands of Praslin and La Digue) (CORDIO, 2005).

The granitic reefs in the Seychelles exhibited very little damage as a result of their energy resistant, rocky foundation (CORDIO, 2005). For example, Grand Rocher, Pointe Police, Port Launay and West Rocks reported <1% damage to the reef (Abdulla & Obura, 2005). Many of the carbonate reef structures, however, were already weakened as a result of the 1998 and subsequent bleaching events. Consequently, the easily moved unconsolidated rubble abraded living coral and broke branching corals – as a result, coral mortality in some areas approached 100% (CORDIO, 2005).

6.2.3 Cumulative Impacts

Coral extent, condition and viability can be strongly influenced by a variety of drivers, and the ultimate condition and extent of coral depends on the interaction between and the cumulative effects of these different drivers. In some cases, a single driver will not have a major influence on the coral, but when combined with other factors can have a substantial effect.

An illustration from Gilby et al (2016), reproduced at Figure 6-2, demonstrates a typical network of interactions that contribute cumulatively to the condition of a coral reef. Key elements from a general Seychelles perspective are outlined below, noting that climate change is just one of the effects that contribute to overall reef condition.

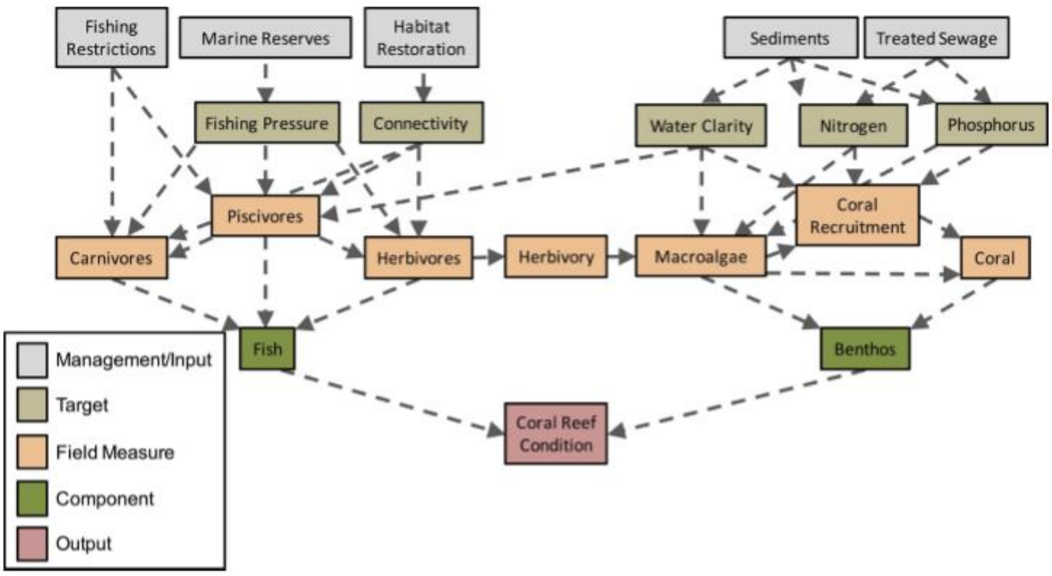


Figure 6-2 Conceptual model showing multiple drivers which collectively affect coral condition (From Gilby et al. 2016)

6.2.3.1 *Fishing*

Fishing is one of the most important reef-related economic activities in the Seychelles, with reefs around the granitic islands experiencing heavy fishing (Ahamada, 2008). Although not a major impact in comparison to major bleaching and storm events, there has been evidence of damage occurring to the reefs when fishermen are laying/removing fishing traps (CORDIO, 2005). Reef trampling also occurs on reef flats during the low tide, where local residents walk the reefs flats looking for octopus. This is particularly evident on the wide reefs flats on the south-eastern part of Mahe (Anse Aux Pins, Au Cap, Pointe Au Sel, and Anse Forbans), but also occurs on La Digue.

While reef trampling can have flow-on effects to coastal zone management (i.e. where reef degradation leads to effects on the shoreline), the reef flats provide an important food source to local communities and is also culturally important. These conflicting user needs may require careful management consideration at some locations, including at prospective coral restoration sites.

6.2.3.2 *Nutrients and Macroalgae*

Land-derived runoff can be a source of elevated nutrient inputs to reefal areas, which can lead to eutrophication and an excessive growth of marine algae in coastal areas. It presumably predominates in the vicinity of agricultural lands, and/or their respective stream outlets but the influence on reef condition is also dependent on water/nutrient retention times (i.e. whether or not a location is well-flushed). Nutrient concentrations have not been quantified in a broad scale manner across the Seychelles, such that there is not currently a clear spatial understanding of where nutrient inputs are a key driver of reef condition.

Even without elevated nutrient concentrations, macroalgae can also be a key driver of reef condition following disturbance and/or degradation. When corals are damaged or in poor health, macroalgae can gain a competitive advantage and increase in cover. Significant increases in macroalgae cover, as might happen after coral bleaching or storm-derived coral damage, can present an obstacle to coral regaining foothold in the affected area.

Note that excessive algal material, and decay thereof, has the potential to cause a reduction in oxygen concentrations (hypoxia) in coastal lagoon areas.

There are trials of approaches and technologies for managing macroalgae on tropical reefs, including a present trial in the Seychelles (PhD student research through the University of Lancaster). These can include, for example: manual removal; mechanically aided removal (e.g. vacuum); promoting herbivory (e.g. by sea urchins). Success can depend on factors such as: the type of algae being targeted (i.e. different methods are suited to different algal morphologies or growth forms, such as turfing algae *vs* foliose algae); labour intensiveness and whether there are resources to support labour intensive approaches; ongoing maintenance regime; and perhaps most importantly, whether the underlying drivers promoting excessive algal growth have been addressed. In the Seychelles there is a company on Praslin Island that collects *Sargassum* spp. wrack from beaches for liquid fertiliser, such that there is a possible financing model for supporting macroalgae management. However, macroalgae in itself is naturally occurring in reef environments (with the exception of invasive species) and provides an important nursery habitat and food source on reef flats for species of fisheries significance. As such, decisions considering macroalgae management would need to consider the beneficial ecological functions of algae.

6.2.3.3 Commercial Use (Boating, tourism)

The anchoring of visiting boats is a minimal damaging impact for coral reefs of the Seychelles. Aldabra research station reports declines in hard-coral cover in the vicinity of the station, and attributes it to the anchoring of visiting boats (Stobart, Teleki, Buckley, Downing, & Callow, 2004). However, efforts have been made to construct mooring buoys in critical coral reef areas to combat these impacts, although many of these are not maintained or not always used.

Other commercial uses of the reefs, such as tourism, have several impacts. Direct impacts include damage from anchors and trampling during snorkelling/diving/recreational activities. Indirect impacts can occur from the construction and operation of commercial-related infrastructure (such as hotels) (CORDIO, 2005). Eden Island (an artificial island hosting a number of luxury apartments, a shopping centre, hotel and small ports) and the reclaimed land at Roche Caiman District, both on the east coast of Mahe, were built during the late 1990s/early 2000s on a coral reef.

6.2.3.4 Reclamation, Mining and Sedimentation

Without proper mitigation and management of reclamation on shallow reef flats, there is a possibility of the associated cumulative impacts (such as sedimentation from dredging) to significantly impact and eliminate coral reefs (CORDIO, 2005). For example, sediment-related stress has been evident at the Sainte Anne Marine National Park as a result of chronic dredging-related activities on the east coast of Mahe since the 1980s (CORDIO, 2005).

6.2.3.5 Disease and Pest Species

In the Seychelles, an abundance of disease/invasive species has not been observed on the reefs (CORDIO, 2005). Populations of crown-of-thorns starfish (CoTS) have been reported since 1996 but have been actively controlled via physical removal. Despite these management efforts, the last outbreak was only brought into check by the 2016 bleaching event. A significant decrease in available food severely reduced their numbers.

Although disease is not widespread or classified as a threat in the Seychelles, black-band and white-band diseases have been observed around Mahe (CORDIO, 2005).

6.2.3.6 Climate Change/Global Warming

Climate change is likely to have a variety of effects on corals. Implications include:

- Increased thermal stress that contributes to coral bleaching and infectious disease.
- Sea level rise: may lead to increases in sedimentation for reefs located near land-based sources of sediment. Sedimentation runoff can lead to the smothering of coral.
- Changes in storm patterns: leads to stronger and more frequent storms that can cause the destruction of coral reefs.
- Changes in precipitation: increased runoff of freshwater, sediment, and land-based pollutants contribute to algal blooms and cause murky water conditions that reduce light.
- Altered ocean currents: leads to changes in connectivity and temperature regimes that contribute to lack of food for corals and hampers dispersal of coral larvae.

- Ocean acidification (a result of increased CO_2): causes a reduction in pH levels which decreases coral growth and structural integrity.

Currently, no concrete studies exist quantifying the exact impacts that an increase in oceanic CO_2 concentrations will have on coral reefs in the Seychelles. However, it has been estimated that the calcification rate of corals, as a result of increasing CO_2 levels, would decrease by approximately 14-30% by 2050 – thus making the ecosystem more vulnerable to disturbance (CORDIO, 2005).

6.3 General Potential Restoration Risks to Consider

There are a variety of risks which need to be considered when planning and undertaking coral restoration.

6.3.1 Operational Risk

Safety (i.e. occupational health and safety) presents a key operational risk that requires consideration for the operation and implementation of any marine project. For example, risks associated with the following should be acknowledged, if applicable, and managed accordingly:

- Safety of divers;
- Safety of personnel working at restoration facilities;
- Working on/around water, boats and tropical marine environments;
- Exposure of personnel to the sun and similar considerations for working outdoors; and
- Manual labour.

Site suitability must be evaluated in terms of general suitability for restoration and, if suitable, which restoration technique would be appropriate for the site. This covers a wide range of potential constraints, such as oceanographic, biophysical, logistical and accessibility, economic, user needs and expectations, navigation, cultural or social constraints, and biodiversity among others.

The availability (or lack thereof) of specialist equipment, skills, personnel, materials or other resources may also present a risk to restoration.

6.3.2 Permits and Approvals

Depending on the type and location of an activity, it may trigger the need for various permits, approvals or exemptions, as relates to the relevant Ministry and legislation. Applications for permits or approvals may be costly, not only in terms of application fees, but also in relation to the application preparation (e.g. professional services, supporting documentation which may require additional studies, stakeholder consultation etc.). The ultimate risk is that a restoration proposal may not be given permission to proceed by regulators.

Even with regulatory permission, success may hinder on factors such as social license to operate and community support. In this sense, effective stakeholder engagement and consultation can be critical to restoration success.

6.3.3 Implementation Risk

These are risks related to the implementation of coral restoration activities. Effective coral restoration takes a significant amount of time and the likelihood of success can be influenced by a variety of external factors (generally similar to the drivers of coral health). It is essential that these are considered early on in the planning and placement of coral restoration (see Section 6) and that high-risk sites are not prioritised for restoration.

Coral restoration works are also highly sensitive to factors such as algal growth which need to be actively managed. This can be labour intensive and expensive, such that management and maintenance costs must be factored into proposals.

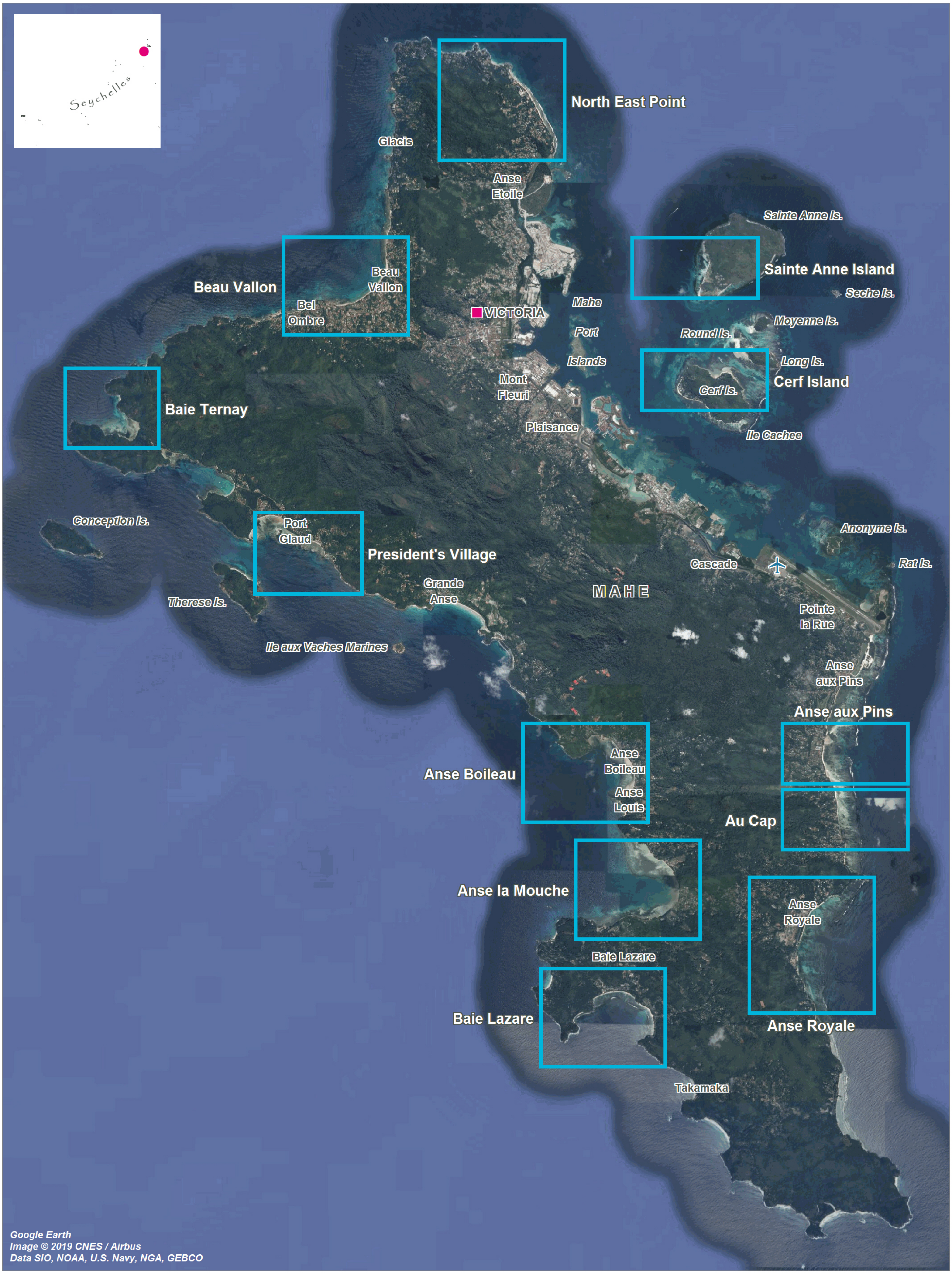
6.3.4 Risks of Unintended Consequences

This covers the potential for unintended consequences to be derived from coral restoration activities. In particular, potential adverse effects to the local marine environmental values should be understood and mitigated. From an ecological perspective, examples include water quality impacts, spills, physical habitat damage, habitat alteration/loss at the expense of non-coral marine values, introducing marine pests or disease (e.g. transplanting of coral species which are not native to the restoration site, or introducing/exacerbating coral disease). Non-ecological examples could include, for example, adverse social/recreational effects, such as excluding human users from a location in order to manage restoration activities. These must be considered in all planning and must be accounted for, monitored and actively managed.

6.4 Ecological Potential and Risks for Each Focus Area

6.4.1 Mahe Focus Areas

An overview of the location(s) of Mahe focus areas is shown in Figure 6-3. Relevant descriptions and a map for each individual focus area are provided thereafter.



Title:

Focus Areas - Mahe

Figure: **6-3**

Rev: **A**

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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6.4.1.1 Anse Aux Pins (CZMU 2)

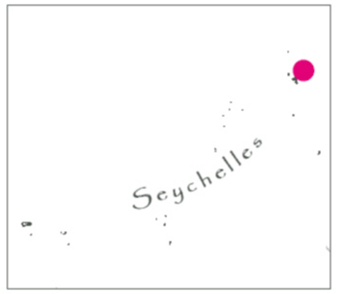
Identified Problem(s): Some of the identified problems in this area (Figure 6-4) include local erosion and flooding during extreme storm and rainfall events (Alvarez Cruz et al. 2011). Parts of a "wetland" in this area have been developed and now increase the risk of exacerbating flooding during high-rainfall periods. Surrounding coral reefs are located approximately 500-650m from the shore and are important near-shore barriers and provide substantial protection from waves, helping to reduce flooding from storms and erosion, however these reefs are degrading after multiple bleaching events and wave run-up reduction is low in the north rising to severe in the south (Deltares, 2018).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion.

Limitations to Coral Reef Restoration: It is assumed that there is little live hard coral cover based on sites surveyed further south, which in turn means little coral recruitment likely to be available. Bedrock at this site is covered in macroalgae resulting in little substrate available for whatever coral recruitment there might be. Dense, fast-growing macroalgal beds also pose a threat to slow-growing corals via competition for space. There is substantial human impact on the reef flats in the form of fishing (boats and traps) and reef trampling (for octopus). Based on fishing activities in the area, it is assumed that there are few herbivorous fish to help control macroalgae. There is also nutrient in-put into the system via run-off from high-residential area, likely exacerbating the growth of macroalgae on the reef flats. South-east trade winds cause rough sea conditions between May – October each year, likely to impact any reef restoration work through the growing or transplanting or corals.

Opportunities for Coral Reef Restoration: Unlike some areas further south, the reef flat is somewhat deeper here (1-2 m) and would be more suitable to corals, however the other limitations listed above are likely to out-weight this opportunity.

Potential Options: A better understanding of the benthic environment on the reef slope is needed. If coral cover is extremely low (as expected) and the reef crest is likely to collapse, possible near-shore interventions could include submerged break-waters preferably of a hybrid nature to provide both a solid, permanent three-dimensional structure which will form a stable base for coral transplantation. Coral-restoration on the reef-flat is unlikely to work unless human impact in the area can be controlled/managed.



LEGEND

- Stream Outlets
- Fish Landing Sites
- Coastal Erosion Sites
- Sea Walls
- Seagrass and Macroalgal Beds
- Trade Winds
- Urban Areas
- Reefs

Title:

Annotated image of Anse aux Pins showing oceanic biological processes and other variables that may affect coral health

Figure: 6-4

Rev: A

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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6.4.1.2 Au Cap (CZMU 3)

Identified Problem(s): Some of the identified problems in this area include local erosion and flooding during extreme storm and rainfall events (Alvarez Cruz et al. 2011) (Figure 6-5). Construction of sea walls in several sections has helped address the historical erosion, but some local erosion of beaches continues. Reduction in wave run-up is moderate to severe in the northern sector (Deltares 2018). Surrounding coral reefs are located approximately 300-650m from the shore and are important near-shore barriers, providing substantial protection from waves, and helping to reduce flooding from storms and erosion. These reefs are likely degrading after multiple bleaching events.

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion.

Limitations to Coral Reef Restoration: The reef flat in this region is extremely shallow (0.5-1m) and much of it near the shore is exposed during the spring low tides. Patch reefs closer to the reef crest get very shallow during the low tides, with much of the now dominant macroalgae exposed. RRA surveys found little live hard coral cover, and any live coral that was found was either overgrown with macroalgae or was recently recruited and likely to be overgrown in the future. Given there was not much LHCC, little coral recruitment is likely to be available. Bedrock at this site is covered in macroalgae resulting in little substrate available for whatever coral recruitment there might be. Dense, fast-growing macroalgal beds also pose a threat to slow-growing corals via competition for space. Urchins are abundant on the reef flats, but unlikely controlling algal cover. Few herbivorous fish were recorded and given the fishing activities in the region, are likely depleted and ineffective in controlling the macroalgae.

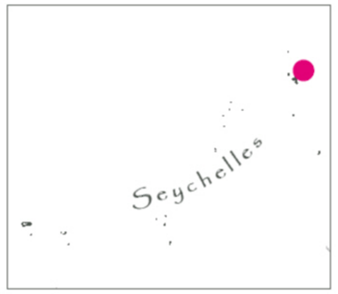
There is substantial human impact on the reef flats in the form of fishing (boats and traps) and reef trampling (for octopus and pole/line fishing). Seagrass beds in some regions appear unhealthy, likely due to prolonged exposure during low tides and trampling by tourist and local beachgoers. There is also nutrient in-put into the system via run-off from high-residential area, likely exacerbating the growth of macroalgae on the reef flats. South-east trade winds cause rough sea conditions between May – October each year, likely to impact any reef restoration work through the growing or transplanting or corals.

There are several stream outlets around Point aux Sel and overflow during heavy rains.

Opportunities for Coral Reef Restoration: No obvious opportunities for coral reef restoration through live corals.

Potential Options: A better understanding of the benthic environment on the reef slope is needed. If coral cover is extremely low on the reef slope (as expected) and the reef crest is likely to collapse, possible near-shore interventions could include submerged break-waters preferably of a hybrid nature to provide both a solid, permanent three-dimensional structure which will form a stable base for coral transplantation.

Coral-restoration is unlikely to work unless human impact in the area can be controlled/managed, and even then, large amounts of macroalgae would first need to be removed and managed on a regular basis. With more information there may be potential for active restoration on the reef slope. The site looks inappropriate for in-situ nurseries so any coral transplantation would need to be done using ex-situ nurseries (potentially located at the university). This would need to be coupled with passive restoration through management of existing reef stressors (unsustainable practices, macroalgae management, nutrient input,) and the necessary community engagement and buy-in.



LEGEND

- Stream Outlets
- Sea Walls
- Seagrass and Macroalgal Beds
- Trade Winds
- Urban Areas
- Reefs

Title:

Annotated image of Au Cap showing oceanic biological processes and other variables that may affect coral health

Figure: 6-5

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6.4.1.3 Anse Royale (CZMU 4)

Identified Problem(s): Some of the identified problems in this area include local erosion and flooding during storm events, mostly in the south (Figure 6-6). Vulnerability to flooding due to severe weather is low to medium (Alvarez Cruz et al. 2011). Salt water intrusion into farmlands in the south has been identified as a problem with a low to moderate reduction in wave run-up predicted in this area (Deltares, 2018). In some places, construction of sea walls has been used to stabilize the coast and road. Surrounding coral reefs are located approximately 200-500 m from the shore. There is a more granitic type reef in the north, and then a reef crest extends across the whole region but is more prominent north of the channel in the bay. These reefs are important near-shore barriers, providing substantial protection from waves, and helping to reduce flooding from storms and erosion. The area also has extensive sea-grass beds which have been shown to have receded over the last 20 years.

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion. Benefit to tourism.

Limitations to Coral Reef Restoration: Recent habitat surveys conducted by UniSey and MCSS in January 2019 (as part of another project) show that there is little live hard coral cover in the northern section of Anse Royale. This is likely to be the case in the south as well, although there are no data to support this. Given there was not much LHCC, little coral recruitment is likely to be available. Bedrock in the north is covered in macroalgae, mostly *Sargassum* and *Turbinaria* spp. resulting in little substrate available for whatever coral recruitment there might be. Dense, fast-growing macroalgal beds also pose a threat to slow-growing corals via competition for space. There is substantial human impact in the region in the form of fishing (boats and traps) and snorkelling. Few herbivorous fish assumed due to fishing activities in the bay. Seagrass beds in the north are virtually absent or patchy, likely due numerous tourist and local beachgoers. There is also nutrient in-put into the system via run-off from high-residential area, likely exacerbating the growth of macroalgae in the bay. South-east trade winds cause rough sea conditions between May – October each year, and strong currents are present around the granitic reef site (i.e. around the island at the granitic site). It is possible that coral reef cover was always limited in this region due to SE trade winds (Graham et al. 2007) did not record high LHCC prior to 1998 bleaching event).

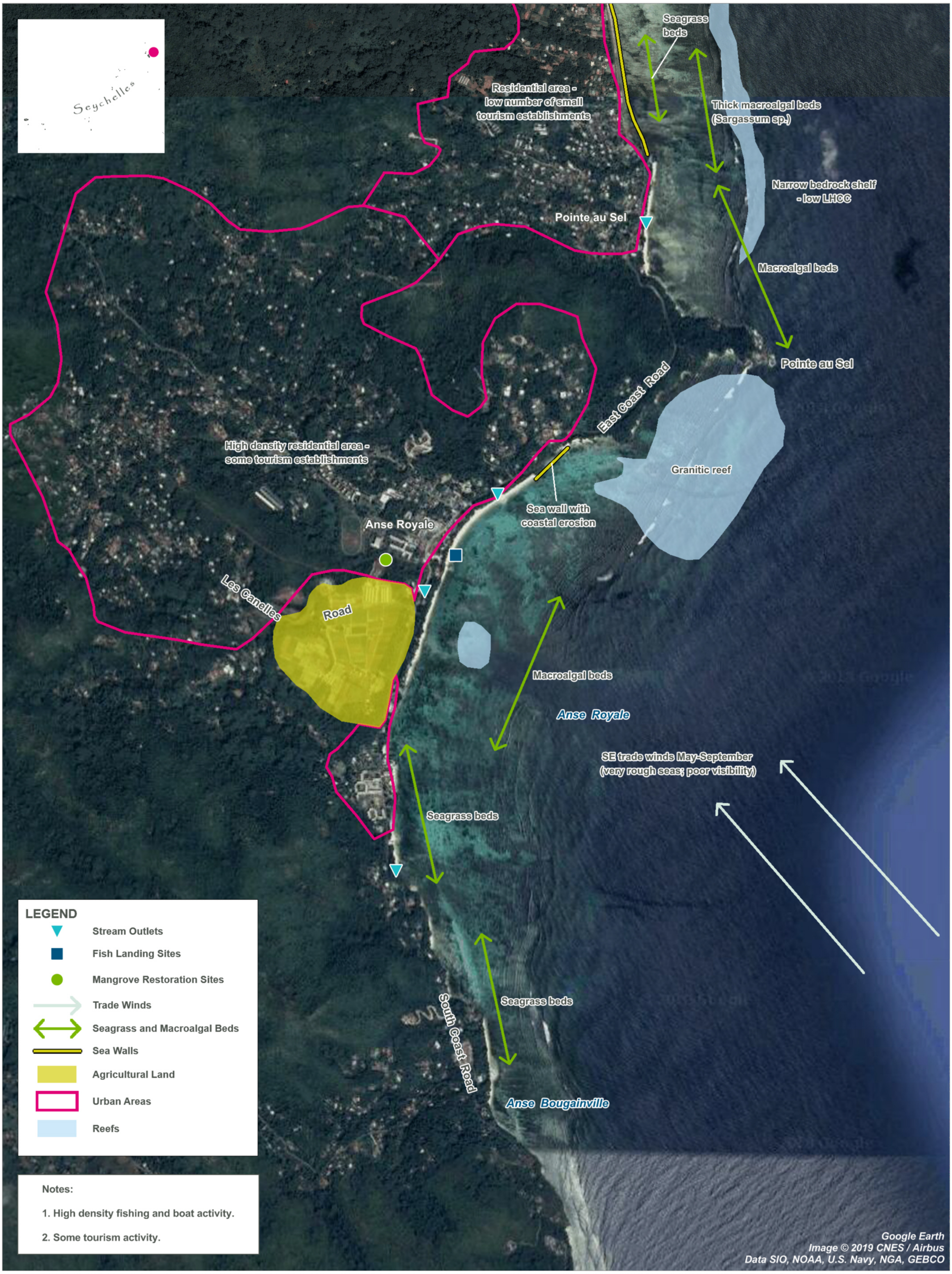
Opportunities for Coral Reef Restoration: The northern part of this region is close to granitic reef, which has some live hard corals, but not much. Depth in and around the bay (inner side of reef crest) ranges from 2-3 m, which would be suitable for coral reef restoration. There are also diverse habitats in the area (granitic reef, seagrass beds and mangroves), and potential for tourist and local resident co-operation. The University of Seychelles is also located here, which could help in raising awareness.

Potential Options: Although SE trade winds in the area cause rough sea conditions, deeper parts of the bay in the north could provide useful area for coral reef restoration. However, this would likely need to be done with macroalgae clearing and management of human impact in the area. Southern parts of the bay are possibly too exposed and/or have higher nutrient inputs from surrounding agricultural land. Submerged break-waters or other submerged barriers, preferably of the hybrid type as described previously, might prove better in the south if human impacts cannot be controlled.

The northern side of Anse Royale exhibits potential for active restoration including:

- Coral transplantation on natural substrate;
- Management of macro algae; and
- Management of human stressors through engagement with the community users and tourists to help mitigate unsustainable and damaging practices at this popular site.

On the southern side, if usable natural substrate is not available, artificial structures (such as the mentioned break waters) could be a viable option. Smart reef structures can offer 3D structure needed to offer coastal protection whilst maintaining other ecosystem functions of a natural reef. New developments in three-dimensional reef substrates have the potential to better replicate reef function, including offering coastal protection, creating habitat, suitable settlement sites that encourage natural coral recruitment (through substrate texture etc.) and with an additional option to transplant coral colonies from a nursery onto the structure. Any such approaches would need to consider the impacts of installing artificial reef/breakwaters to sediment transport processes in the area.



Title:

Annotated image of Anse Royale showing oceanic biological processes and other variables that may affect coral health

Figure: 6-6

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6.4.1.4 Baie Lazare (CZMU 5)

Identified Problem(s): Erosion, wave overtopping, wave run-up and washed-up coral debris have been identified as problems in this region (Figure 6-7). The southern road is particularly prone to erosion and waves. Lowland flooding also a problem with the area listed as having a high vulnerability to flooding in extreme weather (Alvarez Cruz et al. 2011). Reef that was excavated for a main channel in the bay has possible accelerated erosion of the beach. Reef restoration may help with this. There is variable wave reduction potential at this location (Deltares, 2018).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion.

Limitations to Coral Reef Restoration: There is thought to be low hard coral cover in this region, so coral recruitment could be an issue – field surveys would help clarify. Bedrock covered in macroalgae and turf algae, although perhaps not as dense as at Au Cap, but could present an issue of substrate for coral growth. There is some human impact in the bay in the form of fishing (boats and traps, though most boats tend to utilise the southern channel) and seagrass/reef trampling. Few herbivorous fish assumed due to fishing activities in the bay. There is also nutrient in-put into the system via run-off from surrounding area, possibly contributing to algal growth. Water clarity may also be an issue.

Opportunities for Coral Reef Restoration: This region is a low-density residential area although there is still runoff into the system. The bay is mostly protected from the trade winds, and thus coral restoration may be suitable. Bommies/patch reef present in the centre and south of the bay. Note however that the centre and south side of the bay consistently get moderate swell, particularly in the NW season. There are some tourism establishments which could help support or raise awareness about any potential reef restoration. This is considered a definite opportunity for engagement and education through the various tourism establishments (both hotels and guest houses), community recreational users (beach, surf and snorkelling activities) and fishers. It is a popular beach for surfing (centre, south) and snorkelling.

Potential Options: This region is fairly protected from the rough seas caused by the trade winds (compared to regions on the east coast), and near-shore interventions in the bay could help with beach erosion. Possible near-shore interventions could include coral reef restoration or other submerged break-waters/barriers preferably of the hybrid type as described previously.

The south side of the bay includes some patch reef (field surveys required) where natural substrate could be utilised for coral transplantation. Partnerships with local tourism establishments could be used to create an operational base to run in-situ or ex-situ coral nurseries from. Additional potential to up-scale restoration efforts already existing in the area (at Petite Anse).

LEGEND

- Stream Outlets
- Seagrass and Macroalgal Beds
- Wetland
- Urban Areas
- Reefs

Title:
Annotated image of Baie Lazare showing oceanic biological processes and other variables that may affect coral health

Figure: **6-7**

Rev: **A**

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Approx. Scale

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6.4.1.5 Anse a La Mouche (CZMU 6)

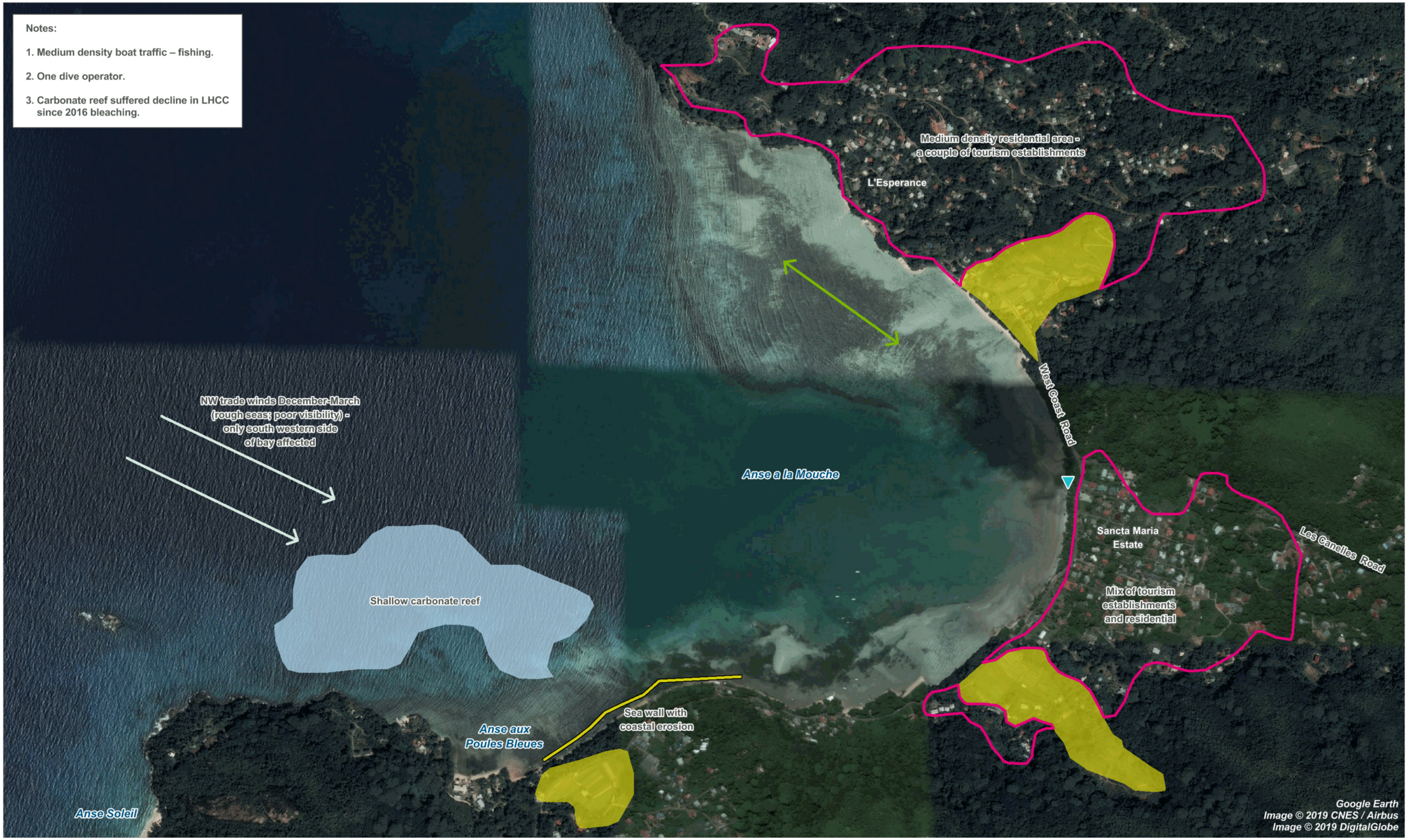
Identified Problem(s): Some of the identified problems in this area (Figure 6-8) include local erosion and flooding during storm events, as well as wave overtopping during high tides and is predicted to have moderate to severe reduction in wave run-up (Deltares, 2018). Flooding with heavy rainfall is also a problem and the area has a high vulnerability to flooding in extreme weather conditions (Alvarez Cruz et al. 2011). The northern section of the bay has shallow water reefs, which provide protection. The southern region is more exposed.

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion. Benefits to tourism – diving operator nearby, utilising three main dive sites in the area with a medium to high frequency of diving/snorkelling visitors.

Limitations to Coral Reef Restoration: Reefs in the north have suffered from the bleaching events and impacts from Crown of Thorns starfish resulting in low LHCC, with subsequent low coral recruitment. There are also human impacts on the reefs and reef flats, mostly fishing. Agricultural lands and medium density residential area mean there is nutrient run-off into the bay.

Opportunities for Coral Reef Restoration: This region is mostly protected from the trade winds (except south-western side of bay) and might benefit from coral restoration in the north.

Potential Options: This region is fairly protected in the north from the rough seas caused by the trade winds and near-shore interventions in the bay could help with beach erosion. Two popular dive sites (Alice and Oscars), in the north and south of the bay, show potential for restoration activity, including transplantation onto the existing natural reef substrate, community and tourist engagement with the local dive school and tourism establishments. Possible near-shore interventions could include coral reef restoration in the north and other submerged break-waters/barriers in the south, preferably of the hybrid type as described previously. There exists potential to up-scale restoration efforts already existing in the area (at Petite Anse).



LEGEND

- Stream Outlets
- Sea Walls
- Seagrass and Macroalgal Beds
- Trade Winds
- Agricultural Land
- Urban Areas
- Reefs

Title:

Annotated image of Anse la Mouche showing oceanic biological processes and other variables that may affect coral health

Figure: 6-8

Rev: A

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6.4.1.6 Anse Boileau (CZMU 8)

Identified Problem(s): Some of the identified problems in this area include erosion and flooding during spring high tides and during storms/heavy rainfall (Alvarez Cruz et al. 2011) (Figure 6-9). Wave overtopping onto roads also occurs and the area is predicted to have a moderate reduction of wave run-up (Deltares, 2018). Small patches of reef help disperse wave energy.

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion.

Limitations to Coral Reef Restoration: Little knowledge of reefs in this section. Some human impact (mainly fishing, but possibly also reef trampling). Agricultural lands and medium-density residential area mean that there is some nutrient run-off into the bay and could accelerate algal growth.

Opportunities for Coral Reef Restoration: This region is mostly protected from the trade winds and other habitats exist e.g. seagrass beds and mangroves. Mangrove restoration already taking place, so there could be potential for community buy-in for reef restoration if needed. The wide deep passage at the northern end of the bay is used by larger fishing vessels to access the inshore anchorage behind the reef crest so restoration should be limited to the middle and southern sections.

Potential Options: This region is fairly protected from the trade winds and near-shore interventions in the bay could help with beach erosion and flooding. Possible near-shore interventions could include coral reef restoration but would depend on what reef already exists – more information needed.

LEGEND

- Stream Outlets
- Fish Landing Sites
- Seagrass and Macroalgal Beds
- Agricultural Land
- Urban Areas
- Wetland
- Mangrove Restoration

Title:
Annotated image of Anse Boileau showing oceanic biological processes and other variables that may affect coral health

Figure: 6-9

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6.4.1.7 President's Village (CZMU 9)

Identified Problem(s): The major problem identified here is coastal erosion due to exposure to the SE trade winds and swell patterns. Fringing reef exists about 100-200m from the shoreline and helps protect the coastline but a significant section of the coast has been armoured with a concrete wall to protect the road from erosion. This area is in the zone identified as the most at risk of potential flooding due to extreme weather in the inner islands (Alvarez Cruz et al. 2011). There is low potential for wave runup reduction at this location (Deltares, 2018).

Objectives of Coral Reef Restoration: Provide l protection from waves, helping to reduce flooding from storms and erosion.

Limitations to Coral Reef Restoration: Little knowledge of reefs in this section, although GVI collect data from Therese Island nearby. Fresh-water input and possibly nutrient run-off in some parts of the region. Exposure during the SE monsoon will limit what types of activities could be carried out. It is also difficult, and potentially dangerous accessing the area from the adjacent shoreline.

Opportunities for Coral Reef Restoration: Unsure?

Potential Options: Possible near-shore interventions could include coral reef restoration but would depend on what reef already exists – more information needed.

6.4.1.8 Baie Ternay

Identified Problem(s): Baie Ternay (Figure 6-10) is national marine park and thus no risk to residential area and infrastructure. However, the low-lying area has been identified as one of the highest risk areas of flooding in extreme weather conditions (Alvarez Cruz et al. 2011). Beach erosion could be a problem with degradation of carbonate reef system in centre of the bay while reduction in wave run-up is moderate (Deltares, 2018).

Objectives of Coral Reef Restoration: Tourism & biodiversity conservation.

Limitations to Coral Reef Restoration: There is low LHCC in this region since the 2016 bleaching event, and large amounts of tourism (snorkelling and diving). Rough seas are experienced during the N-W trade wind season (December – March). Parrotfish and outbreaks of COTS could pose a potential limitation to any reef restoration.

Opportunities for Coral Reef Restoration: Granitic reefs on either side of the bay may provide decent hard substrate for coral recruitment. Baie Ternay is a national marine park and thus there is little fishing activity (in theory) and little-to-no reef trampling, which would be beneficial for any reef restoration activities. The area was also one of the most prolific areas of coral in Seychelles prior to the beaching events and had one of the highest diversities of corals found in the inner islands (SEYMEMP). There are also a diverse number of habitats in the region including granitic reefs, seagrass beds and mangroves, to help support health reefs.

Potential Options: This region provides a suitable area for coral restoration due to its location and little human activity and there is an existing small-scale restoration project here, run by GVI. Possible near-shore interventions could include coral reef restoration.

LEGEND

- Stream Outlets
- Seagrass and Macroalgal Beds
- Trade Winds
- Reefs

Title:
Annotated image of Baie Ternay showing oceanic biological processes and other variables that may affect coral health

Figure: 6-10

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6.4.1.9 Beau Vallon (CZMU 7)

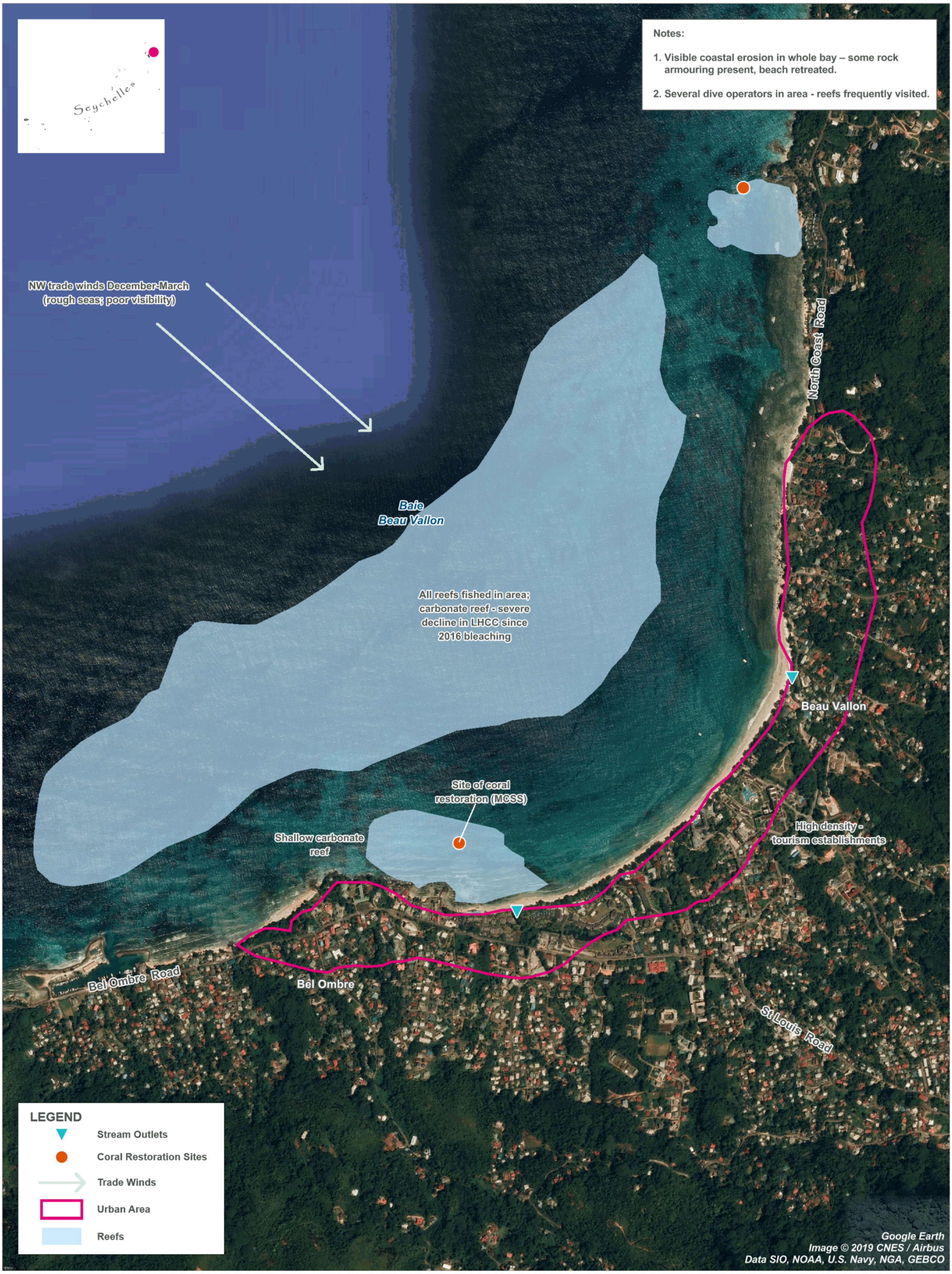
Identified Problem(s): Beau Vallon is a well-known tourist beach with high residential tourist establishments (Figure 6-11). Seasonal erosion threatens the beach profile and road infrastructure causing sea-walls and rock armouring at the Northern end of the beach. In the centre and Southern end of the beach erosion and overtopping have prompted the installation of wooden piling terraces to protect infra-structure. The wave run-up predictive model suggest this area has one of the greatest run-up reductions predicted in the inner islands (Deltares, 2018) due to the absence of any reef structures in the centre of the bay. Construction of hotels has impacted wetland capacity in the past, as well as surrounding reefs. However, the area is predicted to have low vulnerability to flooding during extreme weather events (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce flooding from storms and erosion. Benefits to tourism, fishing.

Limitations to Coral Reef Restoration: There is low LHCC in this region since the 2016 bleaching event, and large amounts of tourism (snorkelling and diving), as well as fishing. Rough seas are experienced during the N-W trade wind season (December – March). Hotel construction and reduction in wetland capacity has impacted some reefs through increased sedimentation. Although reef restoration is occurring in some places in the bay, it is small-scale and parrotfish and outbreaks of COTS pose potential threats.

Opportunities for Coral Reef Restoration: There is some granitic reef in the area and small-scale reef restoration has already begun in the east and the west of the site. There is likely to be support from a number of hotels for reef restoration.

Potential Options: This region provides a suitable area for coral restoration due to its location and suitable depth. Possible near-shore interventions could include up-scaling the coral reef restoration that has already begun. The introduction of a submerged hybrid structure in the centre of the bay may help to reduce wave height and thus erosion of the beach.



Title:
Annotated image of Beau Vallon showing oceanic biological processes and other variables that may affect coral health

Figure: 6-11

Rev: A

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0 400 800m

Approx. Scale

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6.4.1.10 North East Point (CZMU 1)

Identified Problem(s): Identified problems in this area include long-term erosion, wave run-up and wave overtopping onto low-lying coastal roads (Figure 6-12). There are large shifts in sediment and beach profile throughout the year, which is not uncommon on Mahe. Seasonal longshore transport of sediment is driven by south-east and north-west trade winds. Loss of coral reef in the area, and land reclamation in the south have impacted longshore transport and reduced sediment supply in the south. The potential for wave runup reduction is variable at this location (Deltares 2018).

Objectives of Coral Reef Restoration: Provide protection from waves.

Limitations to Coral Reef Restoration: There is a fringing reef and patch reefs offshore; hard coral cover is low on the reef crest a with bare limestone pavement with medium and low-density algae (*Turbinaria* & *Padina* spp.) with a few pockets of medium density coral and a band of medium density coral to the northern end. The middle part of the reef is characterised by low coral cover. Reef restoration is unlikely to contribute to coastal protection unless substantial hybrid structures are placed to dissipate water movement patterns. Location is exposed to swells in southeast throughout the year.

Opportunities for Coral Reef Restoration: Only on substantial hybrid structures.

Potential Options: Coral reef restoration is not recommended for this region unless significant wave and current reducing measures are introduced. The longshore currents and sand movement have been significantly altered following land reclamation in the south, which also removed the main source of sand replenishment and consequently coral restoration on its own is unlikely to contribute to coastal protection.

LEGEND

Trade Winds

Urban Areas

Title:

Annotated image of North East Point showing oceanic biological processes and other variables that may affect coral health

Figure: **6-12**

Rev: **A**

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6.4.2 La Digue Focus Areas

6.4.2.1 La Passe (aka La Passe CZMU 11 and La Passe South (EZMU 11))

Identified Problem(s): Coastal erosion is the main problem in this zone (Figure 6-14). The reef is located 250-300m from the shoreline and loss of reef could lead to local flooding and further erosion. The area is predicted to suffer a moderate to high reduction in wave run-up (Deltares, 2018). The area is classified as one of the highest vulnerability to flooding due to extreme weather (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion. Benefits to tourism – diving and snorkelling.

Limitations to Coral Reef Restoration: The reef flat in this region is extremely shallow (0.5-1 m) and much of it near the shore is exposed during the spring low tides. RRA surveys found little live hard coral cover, suggesting little coral recruitment is likely to be available. Bedrock at this site is covered in turf algae and zoanthid mats, as well as sea grass, resulting in little substrate available for whatever coral recruitment there might be. Few herbivorous fish were recorded possibly due to fishing activities in the region, although none were witnessed during the site visit. There is likely to be human impact on the reef flats in the form of fishing (boats) and reef trampling (for octopus). There is also nutrient in-put into the system via run-off from high-residential area, likely exacerbating the growth of macroalgae on the reef flats. North-west trade winds cause rough sea conditions between December - March each year.

Opportunities for Coral Reef Restoration: No obvious opportunities for coral reef restoration through live corals on the reef flat.

Potential Options: A better understanding of the benthic environment on the reef slope is needed. If coral cover is extremely low on the reef slope (as expected) and the reef crest is likely to collapse, possible near-shore interventions could include submerged break-waters or other submerged barriers, preferably of the hybrid type as described previously. Coral-restoration on the reef flat is unlikely to work because of shallow nature of the reef flat, but could possibly work along the reef slope. If coral transplantation is possible on the slope nurseries would need to be situated in an alternative in-situ location (slightly deeper and less exposed) or the use of ex-situ tank nurseries would be needed.

Title:

Focus Areas - La Digue

Figure: 6-13

Rev: A

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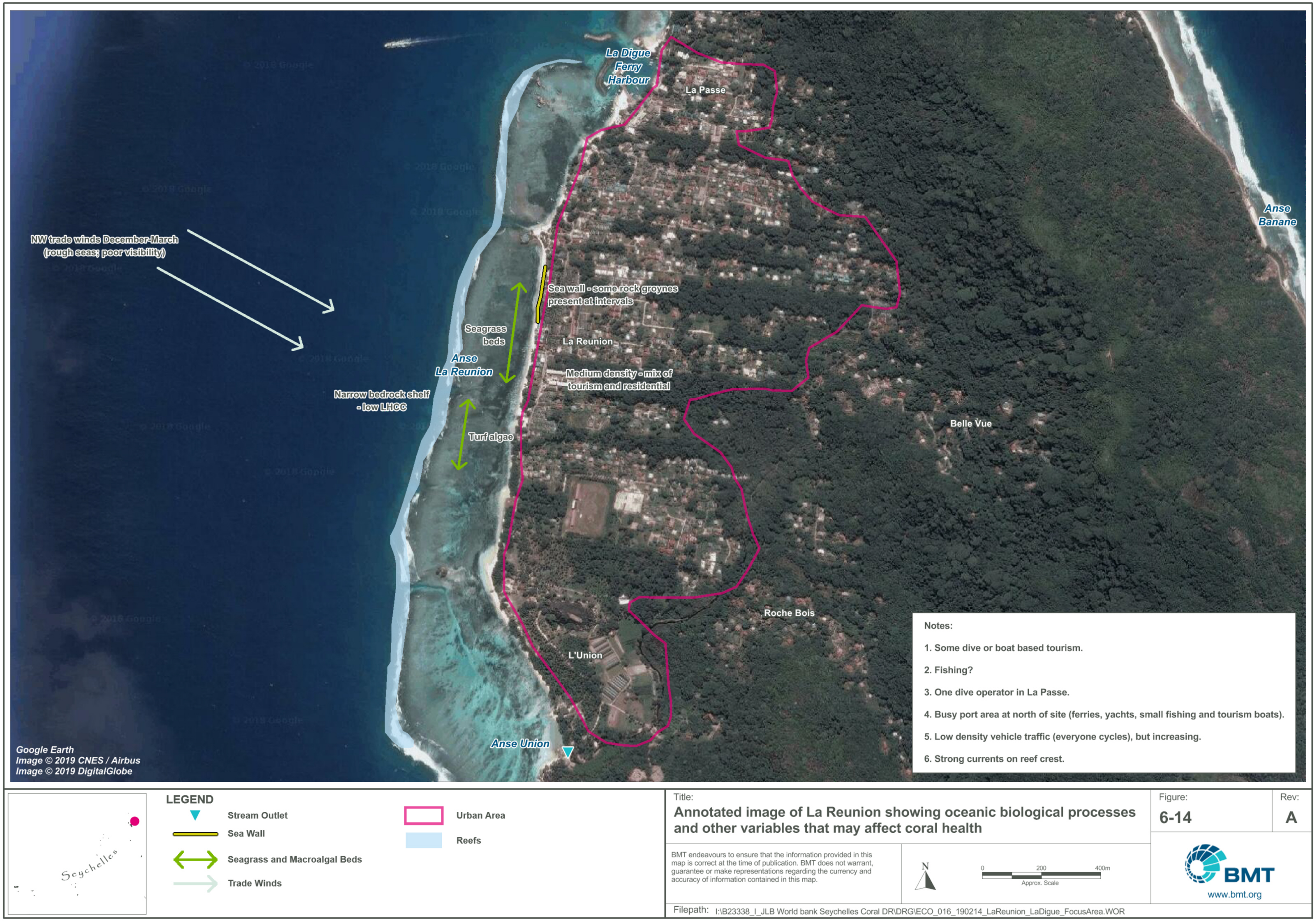

Title:
Annotated image of La Reunion showing oceanic biological processes and other variables that may affect coral health

Figure: 6-14

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6.4.2.2 Anse Severe (CZMU 12)

Identified Problem(s): Coastal erosion is the main problem in this zone (Figure 6-15). The reef is located 80-100m from the shoreline and loss of reef could lead to local flooding and further erosion. The area is predicted to suffer a low to moderate reduction in wave run-up (Deltares, 2018). The area is classified as one of the highest vulnerability to flooding due to extreme weather (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion. Benefits to tourism – diving and snorkelling.

Limitations to Coral Reef Restoration: The reef flat in this region is extremely shallow (0.5-1m) and much of it near the shore is exposed during the spring low tides. Although no surveys were done here, we expect that there is little live hard coral cover. Bedrock at this site is also covered in turf algae and sea grass. No information available on fish and urchins. There is thought to be some human impact on the reef flats in the form of reef trampling (for octopus). North-west trade winds cause rough sea conditions between December - March each year.

Opportunities for Coral Reef Restoration: Low density residential area, with little human impact. However, other than this, no obvious opportunities for coral reef restoration through live corals on the reef flat.

Potential Options: A better understanding of the benthic environment on the reef slope is needed. If coral cover is extremely low on the reef slope (as expected) and the reef crest is likely to collapse, possible near-shore interventions could include submerged break-waters or other submerged barriers, preferably of the hybrid type as described previously. Coral-restoration on the reef flat is unlikely to work because of shallow nature of the reef flat, but could possibly work along the reef slope.

LEGEND

- Seagrass and Macroalgal Beds
- Trade Winds
- Urban Areas
- Reefs

Title:

Annotated image of Anse Severe showing oceanic biological processes and other variables that may affect coral health

Figure: **6-15**

Rev: **A**

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6.4.3 Praslin Focus Areas

6.4.3.1 Anse Consolation (CZMU 14)

Identified Problem(s): Coastal erosion is the main problem in this zone. Loss of reef complexity would like make the area prone to flooding and further erosion. The area has potential for moderate reduction in wave run-up (Deltares, 2018). The area is classified as one of the highest vulnerability to flooding due to extreme weather (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion.

Limitations to Coral Reef Restoration: Little information about the reef in this region although a fringing reef exists of unknown status with some isolated granitic outcrops. Location is southeast facing, exposed to strong winds and swell in season.

Opportunities for Coral Reef Restoration: Low residential area and thus possibly little nutrient run-off. Nearshore appears to have suitable depth for reef restoration, although South-east trade winds could create rough conditions between May – October.

Potential Options: A better understanding of the benthic environment is needed.

6.4.3.2 Grand Anse (CZMU 15)

Identified Problem(s): Coastal erosion is the main problem in this zone. Reef is located in patches with no clear reef crest with patch reefs further off shore. The area has potential for moderate to severe (in the centre) reduction in wave run-up (Deltares, 2018). The area is classified as one of the highest vulnerability to flooding due to extreme weather (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion. Benefits to tourism – diving and snorkelling.

Limitations to Coral Reef Restoration: Little information about the reef in this region. North is seagrass dominant area, typically with coral only dominating along the very edge of reef.

Opportunities for Coral Reef Restoration: Sheltered location and low-medium residential area with a number of hotels with the possibility of buy-in for reef restoration.

Potential Options: A better understanding of the benthic environment is needed.

6.4.3.3 Anse Kerlan (CZMU 16)

Identified Problem(s): Longshore erosion and flooding of roads is a problem in this zone with a series of groins installed to slow sediment flow and rock armouring and a sea wall to protect road infrastructure. The area has potential for moderate reduction in wave run-up rising to severe at the southern end (Deltares, 2018). The area is classified as one of the highest vulnerability to flooding due to extreme weather (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion. Benefits to tourism – diving and snorkelling.

Limitations to Coral Reef Restoration: Little information about the reef in this region. Southeast facing so exposed to swell.

Opportunities for Coral Reef Restoration: In 2013 southern edge of site to north edge of Grand Site had healthy coral growth (e.g. large tabular *Acropora*). While there is a deep channel to south with strong currents, this may also provide cool upwelling.

Potential Options: A better understanding of the benthic environment is needed.

6.4.3.4 Anse Boudin (CZMU 17)

Identified Problem(s): Highly degraded reef. Erosion on specific parts of the road has been identified as a problem with consequent rock armouring. The area is classified as one of the highest vulnerability to flooding due to extreme weather (Alvarez Cruz et al. 2011). The potential for wave run-up reduction is unknown at this location (Deltares, 2018).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion. Benefits to tourism – diving and snorkelling.

Limitations to Coral Reef Restoration: Strong wave action. Little LHCC since 2016 bleaching event (data likely available from Prof David Smith, University of Essex). Potential impacts from hotels e.g. increased nutrients?

Opportunities for Coral Reef Restoration: Low density area with little run-off (?), nearshore mostly protected from waves, but could be impacted by storms during NW Monsoon. Falls within Curieuse National Marine Park, therefore there is an existing mechanism for affording some protection, and is important for tourism. SNPA already doing reef restoration on other side of the channel, off Curieuse Island.

Potential Options: Calm conditions and previously high LHCC along this coastline suggest coral restoration would be possible. Coral recruitment likely to be low after 2016 bleaching event though. Data on LHCC should be requested from Uni Essex.

6.4.3.5 Cote D'Or (CZMU 18) (Anse Volber)

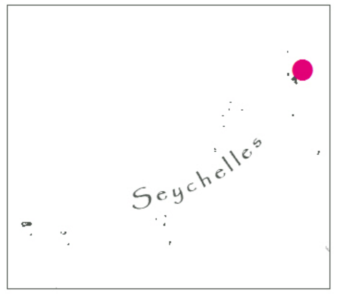
Identified Problem(s): Erosion identified as a problem on north-west section.

Objectives of Coral Reef Restoration: Unknown.

Limitations to Coral Reef Restoration: Little information about the reef in this region which appears to be a submerged fringing structure for most of the length of the beach. Large amounts of algae wash up during south-east monsoon season, possibly indicating algal abundance in the nearshore. Lots of boat traffic (fishing, dive operators, tour guides etc.). There is high potential for wave runup reduction at this location.

Opportunities for Coral Reef Restoration: Unknown, but SNPA already doing reef restoration on other side of the channel, off Curieuse Island.

Potential Options: A better understanding of the benthic environment is needed – not sure this is really a priority area, or suitable for reef restoration given boat traffic?



Title:

Focus Areas - Praslin

Figure: 6-16

Rev: A

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7 Restoration Potential Framework

The focus of coral restoration activities needs to be directed by a variety of socio-economic, environmental and ecological factors. Most of these will be key considerations of Stage 2. However, this section focusses on the ecological considerations that must be assessed. A recent paper has shown that recovery potential relies on a range of factors and varies between reefs. This can make it very difficult to accurately predict outcomes and to prioritise management actions (Graham et al 2015). It is essential therefore to develop and implement monitoring plans which enable a flexible and responsive approach to be taken to help ensure success. The ultimate business cases for restoration activities will need to be underpinned by information about the likely biophysical outcomes and by the approach to manage the program to maximise potential of success.

7.1 Framework Development

The rationale for the restoration activities must be identified early in the process as will be a key determinant of the scale of what is required and the approach(s) that are needed to achieve successful outcomes. Examples are listed in Table 7-1.

Table 7-1 Why is restoration required?

Key reasons for coral reef restoration:
• Coral reefs occur there, but are damaged or degraded (fishing, cyclone, bleaching, crown-of-thorns starfish etc)
• Coral reefs have occurred here in the past but have been lost due to significant catastrophic impact
• Reefs that provide or have provided ecosystem services (e.g. erosion reduction) have been damaged or lost
• Reef biodiversity values have been compromised
• Fishing or tourism values of the reef have been degraded with associated loss of income for local communities

As mentioned above there is no simple procedure that can be used to determine priority sites. In Table 7-2 below, we provide a series of factors that should be considered and which can help to determine appropriate restoration locations and importantly restoration approaches. Essentially we ask, where there are a variety of sites that require restoration or restoration, what are the physical, biological and ecological criteria that should be considered to ensure desired outcomes can be achieved? Working through these questions can help to determine whether the biophysical characteristics of the restoration are likely to be achieved.

These criteria will be used in conjunction with cost benefit criteria in Stage 2 to support site selection, and to underpin the business case for restoration activities.

Table 7-2 Physical, biological and ecological criteria that should be considered to ensure desired outcomes from coral reef restoration can be achieved?

Short-listing criteria for coral reef restoration	Rationale
Have clear objectives for the reef restoration exercise been clearly identified?	These will help to determine the appropriate techniques that are required. For example, species diversity, habitat diversity and structural diversity (rugosity) may all be important for a site and may require different approaches for restoration. If these are not clearly established, it is impossible to set up an adaptive framework and adjust restoration and management approaches. These objectives ensure that the projects are suitably framed and enable success of the project to be assessed and reported.
What is the optimal scale of reef restoration at the target site that will achieve the desired objectives and be sustainable into the future?	This is essential to plan a holistic restoration program. Achieving restoration outcomes at a large scale is difficult and needs detailed planning. Additionally, if the appropriate scales are not determined it, the desired outcomes from the restoration may not be attained.
What are the wave climate and strength of ocean currents in the area? Is the wave climate conducive to coral growth?	If this is not known there is potential for poor decisions to be made about site selection, and the potential for coral restoration will be reduced in high energy environments.
What is the wave run-up reduction potential?	This is an important consideration in the Seychelles where wave run-up reduction is a critical ecosystem service provided by nearshore coral reefs.
What habitat assemblages are present in proximity to the target area?	Diverse habitats are positive. The surrounding seascape is important as supports diversity of species which may use the reef for some or all of their life history (Olds et al.2014).
Are there other existing reefs in or surrounding the target area? What is the condition of these reefs, what stress are they under from other pressures? Are these reefs in the proximity which are able to seed future populations?	Connectivity to different habitat types and also to other existing reefs is important as supports supply of larvae and other colonising taxa. If these are highly degraded they compromise the potential for recovery, or limit restoration outcomes directly to what can be achieved through coral restoration techniques alone (Mumby and Hastings, 2008). Connectivity with other reefs can potentially support transmission of invasive species.
What is the ecological history of the target site?	This may be difficult to assess and may need reference sites to be surveyed. These sites can also help with understanding why the coral at the target sites has been lost.
What is the depth of the target site(s)?	Should be similar to the growth conditions suitable to the target species. Target sites which are not at the depths suited to particular corals may reduce potential for successful outcomes because of different light regimes etc.

Short-listing criteria for coral reef restoration	Rationale
What is the structural nature of the area (rock, rubble etc)?	This can help to determine the types of reef restoration which may be possible or required at the location. Rubble locations may require rubble stabilisation approaches and also a focus on rugosity, while rocky substrates with existing structures may be more suited for coral fragmentation approaches.
What is the water quality of the area (including temporal variability)?	Locations with poor water quality (high nutrient, turbid water or lower salinity, will not be conducive to coral growth and will reduce likelihood of success.
What is the intended use/level of protection of the area?	Protected sites generally receive less pressure from fishers and visitors, and importantly have better intact and diverse fish communities (herbivores being important (Mumby et al. 2007, Olds et al. 2014).
Are there reefs which are in good condition, but which may need assistance to grow higher in the water column and ensure they are viable in the face of sea-level rise?	The continuing and steadily increasing implications of climate change must be considered in restoration planning. Coral reefs should be supported to maintain similar depths as sea-level rise continues. Restoration can help to support this. These target sites may be situated where there are lower incidences of other pressures and where corals have withstood other pressures such as coral bleaching in the past.

Restoration should also integrate elements of adaptive planning and management of coral restoration projects. Adopting an adaptive (risk based) framework to planning and managing coral restoration projects is essential (e.g. Rissik et al. 2014). It enables the unique aspects of target area to be understood and accounted for and increases the likelihood that outcomes will be achieved. The whole-of-cycle adaptive management approach must be considered as part of the project/program funding. The iterative nature of adaptive management facilitates learning by doing and for adjustments to be made over time in response to changes to drivers, changes in coral growth trajectories and in response to the achievement of desired outcomes form the project.

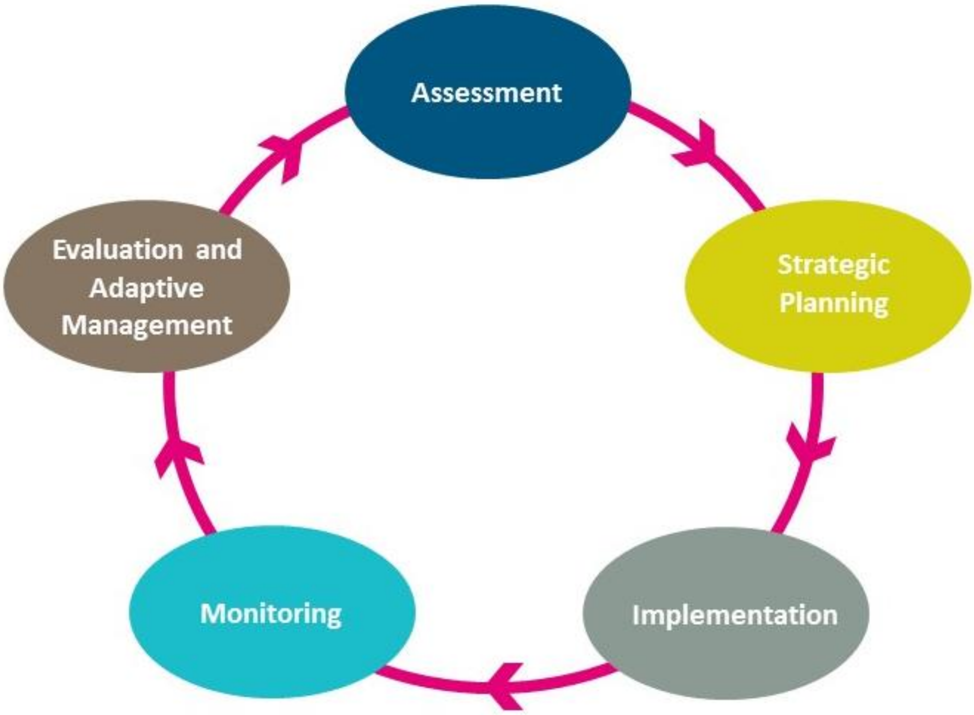


Figure 7-1 Example of Adaptive management framework which for application to ensure successful outcomes from coral restoration activities.

7.2 Data Availability Considerations

It is prudent to make a note here regarding data availability (or lack thereof) in the context of supporting decision making around coral restoration in the Seychelles. There are a large number of bays and beaches in the Seychelles where coral restoration could be considered. Local knowledge and a review of available literature and information indicates that there is a dearth of data and information about many of these sites. This impacts the certainty with which we are able to recommend suitable sites for coral restoration. Where data is not available, we have reduced the certainty about the potential for restoration and have made recommendations about gathering additional information to support decision making.

7.3 Preliminary Prioritisation (Ecological/Coastal)

Our preliminary framework application to key Seychelles focus areas provides a first pass assessment of coral reef restoration potential, based only on environmental and/or bio-physical criteria (i.e. excludes economic/financial, regulatory, user constraints, logistical etc.). Such factors will be added as prioritisation criteria in subsequent stages.

There are valid objectives for coral restoration at every location in this study. The predominant objective is to reduce beach erosion, although in some locations the tourism and fishery potential that can be realised through enhanced reef structure and biodiversity is also a primary objective. The scale at which restoration is required is generally along the entire reef at each location as a result of the significant loss of coral from bleaching events, combined with the continued pressure at most locations from fishers, people trampling on the reef while hunting octopus, and also from tourists. There is little protection in place to reduce pressures although few locations are in marine parks. The beaches are generally faced with a high energy wave environment for part of the year as a result of the trade winds (SE or NW). The monsoon period also impacts some beaches. In some bays part of the reef is protected from the influence of trade winds, with a lower energy environment being present year-round. The habitat diversity varies between locations, some having a range of habitats including wetlands, mangroves, saltmarsh and remnant coral, others have bedrock reefs covered by algae, with low coral cover.

There is a dearth of herbivorous fish at most locations. Little is known about some locations and there is a need for additional data to be collected. Development along the coast ranges from high density housing to low density development. Some areas have roads along the foreshore and there is also tourist infrastructure and accommodation at some locations. In some areas, foreshore protection has been implemented, generally comprising armoured sea-walls to prevent erosion and groynes to reduce long-shore drift of sediment. The runup reduction resulting from reefs has been modelled and is highly variable. Run-up can be reduced by increasing the rugosity of the reefs through coral restoration, but the depths of the reefs needs to be considered. Some are very shallow with limited opportunity for restoration and others are deeper and present a more realistic option.

In general, a number of principles should be followed when selecting priority reefs. These are:

(1) Restoration sites should be actively managed, including removing algal growth, preventing human use of and access to target locations.

(2) Where possible select sites where there is potential for larval supply to augment coral restoration activities.

(3) A range of coral restoration activities should be used to help achieve scale at each location. Some structural input may be required to reduce erosion and to provide additional substrate for coral gardening.

(4) The influence of climate change should be considered. What is the time period over which coral restoration will deliver outcomes? Will this deliver desired outcomes for sufficient time to ensure it is worth the risk of loss in a climate affected future?

(5) Sites with a diversity of habitat types should be prioritised.

(6) External impacts such as nutrient or sediment runoff should be reduced and monitored.

(7) The potential for short, medium, and long-term outcomes from the restoration activities should be considered.

(8) Locations at which multiple benefits can be derived from restoration should be prioritised.

(9) More information about each location should be collected to design the approach, management plan and monitoring activities before restoration is undertaken.

(10) Build on existing successes.

The framework we have produced has enabled us to make a series of bio-physically based recommendations about focus sites for restoration. This is presented in a tabulated format at for Mahe focus areas Table 7-3, and Table 7-4 for focus areas on other islands. Sites have been colour coded, whereby:

- **Blue** shading indicates that restoration should be done at these locations;
- **Yellow** indicates that there is a potential for coral restoration, but that additional approaches and active management are required; and
- **Pink** indicates that coral restoration should not be done at these locations as success is unlikely, or that insufficient information is known about the location.

Most locations exhibit the potential for restoration, but it is highly unlikely that results will be realised at these locations without active management and protection. Sites on small protected or uninhabited islands are appropriate for restoration, but will not deliver outcomes such as foreshore protection or supporting the tourism industry.

Table 7-3 Mahe Focus Areas - Preliminary Prioritisation of Potential Restoration Sites, based on environmental and biophysical potential/risks

	Mahe Focus Areas									
	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Presidents Village	Baie Ternay	Beau Vallon	North East Point
Have clear objectives for the reef restoration exercise been clearly identified?	Yes - wave reduction	Yes - wave reduction	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding). Excavated channel has exacerbated erosion and flooding. Tourism benefit	Wave and flood reduction by increasing coral cover. Tourism benefit	Reduce rates of erosion, wave overtopping and flooding	Yes - prevent coastal erosion (although shoreline already armoured)	Yes - tourism and biodiversity conservation	Erosion and flood reduction, tourism and fishery benefits	Substantial protection from waves
What is the optimal scale of reef restoration at the target site that will achieve the desired objectives and be sustainable into the future?	The entire reef is highly degraded and needs work, particularly on the southern end. The reef has bedrock and coral cover would increase height an rugosity but needs to be supported by a hybrid structure to withstand high energy wave action.	The reef is degraded, and the whole of reef needs to be rehabilitated to provide optimal protection from erosion. Some sea-walls present. The reef has bedrock and coral cover would increase height an rugosity but needs to be supported by a hybrid structure to withstand high energy wave action.	The entire reef is degraded and the whole of reef needs to be rehabilitated to provide optimal protection from erosion. Some sea-walls present. The reef has bedrock and coral cover would increase height an rugosity.	Southern part of the beach particularly prone to erosion and flooding. The area of reef mitigating this would be targeted.	Northern reef suffered from bleaching. Crown of thorns has also impacted. Northern end of reef has shallow reefs which are protected from high energy environment, southern end more exposed.	Middle and southern sections of the reef	Along fringing reef	Restoration at targeted areas along the whole reef.	Central reef restoration would result in reduced wave run-up and associated erosion and flooding.	A submerged central artificial reef / hybrid structure could be established to provide both erosion reduction and tourism potential but the hydrological effects of this would need to be clearly modelled to ensure it did not have negative impacts on other areas
What are the wave climate and strength of ocean currents in the area? Is the wave climate conducive to coral growth?	South east Trade winds cause rough sea conditions between May-October each year	South east Trade winds cause rough sea conditions between May-October each year	SE Trade winds between May to October cause high energy waves. This area may have always had a reduced coral cover.	Erosion exacerbated by management (channel construction)	Most of the bay is protected from trade winds (northern side). Southern areas are more exposed.	Bay is protected from the Trade Winds so has a lower energy environment.	Exposed to SE trade winds and swells.	Exposed to NW Trade winds (December to March)	NW Trade winds May - September.	SE Trade winds May-September. Long-shore drift of sediment occurs here and the source of sand at the bottom of the compartment has been removed, increasing likelihood of erosion.
What is the wave run-up reduction potential (Deltares, 2018)	This location has the highest potential for wave runup reduction on the east coast of Mahe as a result of its wide reef (Deltares. 2018).	Wave runup models undertaken by Deltares (2018) indicate that the wide reefs at this location have a high potential for wave runup reduction. Reduced run-up	Anse Royale has the highest wave runup reduction potential on the east coast of Mahe. This reduces the likelihood of beach erosion and flooding on the	Deltares (2018) reported that the potential runup reduction at Baie Lazare was highly variable as a result of the complexity of the coastline.	Deltares (2018) found that Anse la Mouche had a high runup reduction potential, although this varied across the bay, with the area with no reef having lower potential.	Deltares (2018) reported that there was runup reduction potential at the southern end of the bay, but low runup reduction potential at the northern end of the bay.		Report by Deltares (2018) indicates uncertainty about the depth of the reef at this location. Runup modelling shows variable results, including runoff reduction at the	Wave runup models undertaken by Deltares (2018) indicate that the wide reefs at this location have a high potential for wave runup reduction, although there is a	Deltares (2018) reported that the potential runup reduction at North East Point was highly variable as a result of the complexity of the coastline.

	Mahe Focus Areas									
	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Presidents Village	Baie Ternay	Beau Vallon	North East Point
		decreases the rate of beach erosion and flooding potential.	coast (Deltares 2018).					wider part of the reef (central).	very mild fore reef slope.	
What habitat assemblages are present in proximity to the target area?	Dense fast-growing macro-algal beds which will need management to enable coral growth.	Macroalgae which will need management to enable coral growth.growing on reef. fish only in low numbers.	Extensive (but declining) seagrass beds, macroalgae, mangroves	Bedrock covered by macroalgae. Turf algae also present. Low herbivores due to overfishing. Seagrass beds	Granite reefs, some coral cover, seagrass and macroalgal beds.	Seagrass beds, mangroves, granite reef low coral cover.	Coral and granitic reefs, but additional investigations required.	granitic reefs, seagrass beds and mangroves	corals, nearby coastal wetlands,	Fringing and patch reef, some algal cover.
Are there other existing reefs in or surrounding the target area? What is the condition of these reefs, what stress are they under from other pressures? Are these reefs in the proximity which are able to seed future populations?	little live hard coral cover at sites further south reducing potential for natural coral recruitment	natural coral recruitment potential very low	There are granitic reefs around, low coral cover, unlikely to be a source of coral into the future.	Low hard coral cover in the region. Coral recruitment may be an issue.	coral recruitment an issue	More detailed investigations required to determine whether other coral reefs exist in the area	More detailed investigations required to determine whether other coral reefs exist in the area	Historically one of the most densely coral covered and highly diverse reefs in Seychelles.	No seeding reefs nearby	Some medium density coral that could seed reefs, but strong northwards currents make this unlikely.
What is the ecological history of the target site?	Coral was bleached during previous bleaching events. There is substantial human impact from fishing activities, including trampling for octopus, few herbivorous fish remaining	Coral bleached, covered by macroalgae. Few herbivorous fish	Seagrass beds are declining because of impact from tourists and boat anchoring, few herbivorous fish (overfishing), macroalgae on the reef. Reef likely to be have had low coral cover in the past (pre-bleaching)	Reef excavated to form a channel. Seagrass loss due to trampling.	Bleaching and crown of thorn has affected the area. There are human impacts on the reefs from nutrient runoff as well as large anchorage areas for local boats and fishing vessels.	Sheltered nature of area means there are seagrass beds and mangroves, as well as reefs.	Area affected by heavy rains in monsoon period. Freshwater and nutrient runoff into bay.	Bleaching, Crown of Thorns outbreaks, snorkelling and diving and boat anchoring have impacted reef.	Reefs impacted by bleaching, wetland extent reduced due to development, increasing run-off of sediment to the bay.	Reefs impacted by bleaching. Large areas of wetlands have become overgrown and currently do not provide good filtration; a project is currently underway to remedy this.
What is the depth of the target site?	Reef flat very shallow to the north of the reef, 1-2 metres at the south of the reef	Shallow on reef crest (<1m)	2-3 metres.		shallow northern end	Shallow in near-shore areas.	not sure	shallow	shallow	shallow.
What is the structural nature of the area (rock, rubble etc)?	Bedrock & Rubble	Bedrock & Rubble	bedrock	Bedrock	Bedrock and sand flats	Bedrock and sand flats	bedrock	bedrock	bedrock	bedrock.
What is the water quality of the area (including temporal variability)?	Nutrient input into the system from the surrounding residential area	Nutrients from runoff from high density residential areas.	Water quality is affected by run-off of nutrients from high density residential areas.	Nutrients from residential area. Water clarity a potential issue	nutrients from adjacent agriculture.	Some nutrient input from agriculture and low density residential. Fishing vessel anchorage and loading/un-loading 'port' with attendant issues.	nutrient and freshwater runoff into bay.	Good although there is freshwater run-off which has dictated the extent of the reef.	poor during and following rain events	poor during and following rain events.

	Mahe Focus Areas									
	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Presidents Village	Baie Ternay	Beau Vallon	North East Point
What is the intended use/level of protection of the area?	This is not a protected area, but needs to be if coral restoration is prioritised as human impact will reduce restoration potential. However, such protection is unlikely due to high community usage.	This is not a protected area and is a relatively high use zone and so protection is unlikely	This is not a protected area and gets trampled extensively by tourists and fishers so protection is unlikely due to high community usage.	This is not a protected area and gets trampled extensively by tourists and fishers so protection is unlikely due to high community usage.	Requires protection to prevent access by humans; however, such protection is unlikely due to high community usage.	Requires protection to reduce humans using the reefs to fish and to prevent trampling protection is unlikely due to high community usage.	Human use of any rehabilitated areas would need to be restricted.	Marine Park - fishing and trampling prevented but needs stricter enforcement	Managing human use of reefs, build on reef rehab that is already being done.	Managing human use of reefs.
Are there reefs which are in good condition, but which may need assistance to grow higher in the water column and ensure they are viable in the face of sea-level rise?	no	No	No	No	no	No	not sure	OK but impacted by bleaching	Yes - coral restoration already underway at two sites	no
What are requirements that would support coral restoration?	Human access to the reefs must be regulated and enforced. Fishing regulation may increase herbivores. Hybrid structures would be needed to withstand high energy wave patterns to allow reduction of run up. Development of infrastructure would be necessary to support coral restoration as there are no local NGOs or diving facilities in the area. The shallow reef flat does not allow for local in-water coral nurseries so propagation would have to be done off site	Human access to the reefs must be regulated and enforced. Fishing regulations may increase herbivores Hybrid structures would be needed to withstand high energy wave patterns to allow reduction of run up. Development of infrastructure would be necessary to support coral restoration as there are no local NGOs or diving facilities in the area. The shallow reef flat does not allow for local in-water coral nurseries so propagation would have to be done off site	Diverse habitats in the area make this an important site, where restoration could be implemented. This would need to be done in deeper areas and to the north where there is lower wave energy. Requires active management of algae. Reef restoration would not be focussed on fragmentation, but on provision of submerged breakwaters or barriers. The presence of the University may provide suitable infrastructure to support restoration. Some deeper water areas exist which might allow in-situ coral propagation	Area protected from trade winds, and associated rough seas, making it a candidate site. Coral restoration could include barriers and fragmentation. Although there is no NGO operating directly at this site there are some in the surrounding areas and also a local Dive Centre that could provide infrastructure for restoration activities. Some deeper water areas exist which might allow in-situ coral propagation	Coral restoration on the northern end could help reduce beach erosion. Submerged breakwater in the south could reduce erosion and provide a substrate for corals. Although there is no NGO operating directly at this site there are some in the surrounding areas and also a local Dive Centre that could provide infrastructure for restoration activities. Some deeper water areas exist which might allow in-situ coral propagation	Coral restoration on nearshore reefs. Could build on existing mangrove restoration that is being undertaken. Development of infrastructure would be necessary to support coral restoration as there are no local NGOs or diving facilities in the area.	Exposed during monsoons and the SE trade winds would make this site where successful coral rehabilitation is unlikely. More data on the reef and its coral cover is required. Development of infrastructure would be necessary to support coral restoration as there are no local NGOs or diving facilities in the area.	Suitable for restoration. The presence of an on-site NGO and others locally may provide suitable infrastructure to support restoration. Some deeper water areas exist which would allow in-situ coral propagation	Small scale restoration has already begun at east and west of the site. This could be expanded. The presence of an on-site NGO already undertaking coral restoration would provide suitable infrastructure to support expansion. Deeper water areas exist which allow in-situ coral propagation	Is not likely to result in desired outcomes unless accompanied by substantial structures that help reduce current movement and associated erosion. Development of infrastructure would be necessary to support coral restoration as there are no local NGOs or diving facilities in the area. The shallow reef flat does not allow for local in-water coral nurseries so propagation would have to be done off site

Table 7-4 La Digue, Praslin and Other Focus Areas - Preliminary Prioritisation of Potential Restoration Sites, based on environmental and biophysical potential/risks

	La Digue, Praslin and Other Focus Areas									
	La Passe	Anse Severe	Anse Consolation	Grand Anse	Anse Kerlan	Anse Boudin	Cote D' Or	Petite Soeur	Grande Soeur	Cosine/Cousin
Have clear objectives for the reef restoration exercise been clearly identified?	Erosion reduction, amenity for diving and snorkelling	Erosion reduction, provide habitat for snorkellers and divers to enjoy.	Wave energy mitigation and associated erosion reduction	reduce wave energy and associated erosion. Tourism benefits	Reduce wave erosion, provide tourism benefits	Reduce wave energy, benefits to tourism	Reduce wave energy, benefits to tourism	Biodiversity outcomes	Biodiversity outcomes	Biodiversity outcomes
What is the optimal scale of reef restoration at the target site that will achieve the desired objectives and be sustainable into the future?	entire reef at this site needs to be restored in order to increase rugosity of reef for it to reduce wave runup	Restoration is needed on the reef, although it would need to be restricted to the reef slope.	The entire reef is likely to be the optimal scale, as an increase in rugosity is required to help dampen wave energy.	Reef is patchy, restoration could be targeted at discrete patches.	Beach is actively managed to reduce long-shore drift and to protect road infrastructure	Impacts of erosion on road has resulted in protection (rock armouring)	Erosion on NW section	Reef degraded - high rubble	Reef degraded - high rubble	
What are the wave climate and strength of ocean currents in the area? Is the wave climate conducive to coral growth?	NW Trade winds (December to March each year) cause rough seas and large waves.	NW Trade winds cause rough seas December to March.	South East trade winds May-October.	The area has suffered from erosion due to longshore currents	The area has suffered from significant erosion due to longshore currents with several hard engineered groins developed in an attempt to mitigate	NW Monsoon	south west monsoon	As a small island un-protected island it is affected by wave action during both monsoon seasons	? As a small island un-protected island it is affected by wave action during both monsoon seasons	
What is the wave run-up reduction potential (Deltares, 2018)	La Passe (northern end) and Anse Union (southern end) were identified by Deltares (2018) as having the highest potential runup reduction on La Digue.	Deltares (2018) reported low potential runup reduction at Anse Severe.								
What habitat assemblages are present in proximity to the target area?	Seagrass and zoanthid mats cover the bedrock. Turf algae is present	Little coral cover Seagrass on the bedrock. Turf algae is present	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.	. Reef heavily degraded by bleaching with large areas of macroalgae which will need management to enable coral growth	Large amount of algae washed up on beach at times. Reef heavily degraded by bleaching with large areas of macroalgae which will need management to enable coral growth	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.	
Are there other existing reefs in or surrounding the target area? What is the condition of these reefs, what stress are they under from other	No sites to support coral recruitment. Coral cover along the reef is very low.	No coral reef source for the area	Unknown if there are nearby coral reefs for larval support.	Unknown if there are nearby coral reefs for larval support.	Unknown if there are nearby coral reefs for larval support.	There is reef restoration taking place nearby and a new restoration site and coral nursery are being set up at the	Reef restoration nearby, significant boat traffic	Has a source of larvae, but recruitment low because of movement of rubble	Has a source of larvae, but recruitment low because of movement of rubble	

	La Digue, Praslin and Other Focus Areas									
	La Passe	Anse Severe	Anse Consolation	Grand Anse	Anse Kerlan	Anse Boudin	Cote D' Or	Petite Soeur	Grande Soeur	Cosine/Cousin
pressures? Are these reefs in the proximity which are able to seed future populations?						South of the site. The area used to have very good coral cover.				
What is the ecological history of the target site?	Few herbivorous fish. Reefs impacted by bleaching and by fishing and trampling	No information on fish	No information available	No available information	No available information	Coral bleached, but area falls within national park, good protection.	coral bleached	bleaching	bleaching	
What is the depth of the target site?	0.5-1 m	0.5-1 metre reef crest	no information available	no information available	no information available	no information available	no information available	no information available	no information available	
What is the structural nature of the area (rock, rubble etc)?	bedrock	bedrock	probably bedrock	Patchy reef	Unknown	Bedrock, rubble and coral patches	Bedrock, rubble and some granitic reefs	Bedrock, rubble and some granitic reefs	Bedrock, rubble and some granitic reefs	
What is the water quality of the area (including temporal variability)?	High density residential area nearby leading to nutrient runoff	Low density settlement. Little runoff.	Very low-density residential area.	Low medium residential; several stream outlets with associated run-off during rainy periods		low density residential, large tourism establishment at South of area; little runoff.	low density residential little runoff.	No human use	No human use	
What is the intended use/level of protection of the area?	There is no protection and the reef is heavily used for fishing and hunting octopus.	Some reef trampling for octopus collection, but limited.	No protection, but probably low use zone	Not protected, Management of users required	Not protected, Management of users required	Protected area	lots of boat traffic	Not protected, Management of users required	Not protected, Management of users required	
Are there reefs which are in good condition, but which may need assistance to grow higher in the water column and ensure they are viable in the face of sea-level rise?	no	no	no	No	no	Yes, coral restoration nearby and at South of site.	Yes, coral restoration nearby	Yes (Chong-Seng et al. 2014) However, current status of local reefs is unknown but used to be good before the last bleaching event. Further investigation necessary to establish if any remain	Yes (Chong-Seng et al. 2014). However, status of local reefs is unknown but used to be good before the last bleaching event. Further investigation necessary to establish if any remain	
What are requirements that would support coral restoration?	Very shallow sites meaning that fragmentation approaches are not viable on reef flat. Coral restoration could work on reef slope, but further investigation is necessary.	coral restoration on reef crest unlikely to be successful because very shallow. Potentially on slope, but further investigation necessary.	The low human use and lower pressures makes this a potential restoration site, but more data required Development of infrastructure would be necessary to	Hotels may be a funding source to improve biodiversity on some reef patches. Scale may be appropriate for restoration outcomes. Further	Foreshore already heavily protected. Reef restoration may add little value. Can be done for biodiversity outcomes, but more data and information about	Calm conditions, high past coral cover, suggest rehabilitation possible. The presence of an on-site NGO already undertaking coral restoration would provide suitable	high boat traffic reduces potential for restoration. Although there is no NGO operating directly at this site there are some in the surrounding areas and two local Dive Centres that could provide	Rubble consolidation approaches required Development of infrastructure would be necessary to support coral restoration as there are no local	Rubble consolidation approaches required Development of infrastructure would be necessary to support coral restoration as there are no local	

	La Digue, Praslin and Other Focus Areas									
	La Passe	Anse Severe	Anse Consolation	Grand Anse	Anse Kerlan	Anse Boudin	Cote D' Or	Petite Soeur	Grande Soeur	Cosine/Cousin
	Although there is no NGO operating directly at this site there are some in the surrounding areas and also a local Dive Centre that could provide infrastructure for restoration activities. The shallow reef flat does not allow for local in-water coral nurseries so propagation would have to be done off site	Although there is no NGO operating directly at this site there are some in the surrounding areas and also a local Dive Centre that could provide infrastructure for restoration activities. The shallow reef flat does not allow for local in-water coral nurseries so propagation would have to be done off site	support coral restoration as there are no local NGOs or diving facilities in the area. The shallow reef flat does not allow for local in-water coral nurseries so propagation would have to be done off site	investigation required. Although there is no NGO operating directly at this site there are some in the surrounding areas that could provide infrastructure for restoration activities.	the site is required. Although there is no NGO operating directly at this site there are some in the surrounding areas that could provide infrastructure for restoration activities.	infrastructure to support expansion. Deeper water areas exist which allow in-situ coral propagation	infrastructure for restoration activities.	NGOs or diving facilities in the area. There is deep water which would allow for in-water coral nurseries but these would need to be seasonal to avoid monsoon wave action.	NGOs or diving facilities in the area. There is deep water which would allow for in-water coral nurseries but these would need to be seasonal to avoid monsoon wave action.	

7.4 Prioritisation

Table 7-5 presents a summary of the preliminary prioritisation for the focus areas. For the focus areas assigned a medium priority, note that this indicates that other management actions must be undertaken simultaneously to support restoration and to enable objectives to be achieved. Pink indicates the sites that are unsuitable for restoration, either due to site-specific circumstances, or because sufficient data are not available to support consideration of restoration. Note that these priorities are based on the likelihood of success of coral restoration activities. Medium priorities indicate that coral restoration can be done, but must be done together with a range of other activities and interventions in order to be successful. If stakeholders agree that action and investment is required in these areas, they should be reprioritised, but the broad range of actions required to achieve success must be funded and implemented as well.

Table 7-5 Summary of focus area preliminary prioritisation for coral restoration with relative cost indication.

Location	Preliminary prioritisation	Potential to reduce wave action (Deltares 2018).
MAHE		
Anse aux Pins	Medium priority or additional management required	High
Au Cap	Medium priority or additional management required	High
Anse Royale	Medium priority or additional management required	High
Baie Lazare	Medium priority or additional management required	Variable
Anse La Mouche	Medium priority or additional management required	High in north, variable in south
Anse Boileau	High priority	Low in north, high in south
Presidents Village	Not recommended or insufficient data	Low
Baie Ternay	High priority	Variable
Beau Vallon	High priority	High
North East Point	Not recommended or insufficient data	Variable
LA DIGUE, PRASLIN AND OTHERS		
La Passe	Medium priority or additional management required	High
Anse Severe	Not recommended or insufficient data	Variable
Anse Consolation	Medium priority or additional management required	Low
Grand Anse	Medium priority or additional management required	High
Anse Kerlan	Not recommended or insufficient data	High
Anse Boudin	Medium priority or additional management required	Unknown
Cote D' Or	Not recommended or insufficient data	Low
Petite Soeur	High priority	Unknown
Grande Soeur	High priority	Unknown
Cosine/Cousin	Not recommended or insufficient data	Unknown

7.5 Complementary Management Strategies

There are various management strategies that will likely need to be considered, as applicable to a specific site, in order to enhance the chances of coral restoration success and the achievement of intended objectives of the restoration process. In such cases, it is important to note that success may only be possible if a number of other management techniques are implemented to reduce stress on the system. If these are not implemented then it is unlikely that rehabilitation will be successful. Complementary management strategies that may require consideration are introduced generally below.

7.5.1 Multiple Coral Rehabilitation Approaches

The nature of the target substrate and the surrounding environment will differ within each target location. It is possible that a combination of multiple restoration approaches will be suitable, and should be considered, at some sites (e.g. substrate stabilisation combined with coral fragmentation). This variety will enhance the likelihood of effective coral establishment.

7.5.2 Integration of Engineered Solutions

Coral restoration activities may need to be integrated with engineered solutions to reduce wave energy, and/or provide a substrate for coral colonisation and growth. In many high energy wave environments of the Seychelles, resilience to erosion and wave overtopping (flooding) is only likely to be achieved through a combination of engineered solutions, coral rehabilitation and associated management. Examples of suitable engineered solutions are submerged breakwaters and artificial reefs. Submerged breakwaters have become attractive as coastal protection for recreational and residential coastal areas due to their reduced environmental and visual impact. Since they are underwater, they are less subjected to wave action and consequently not exposed to severe wave breaking. A successful design of submerged breakwaters may also cause beach restoration by trapping natural sediments. Lower construction cost compared with other kinds of detached breakwaters is another advantage. The advantages of submerged breakwaters over conventional structures make them more attractive for protecting natural and developed beaches.

Such structures can be designed so that they can be suitable substrates for coral settlement, rehabilitation and growth. Successful application of engineered structures strongly depends on their accurate and effective design, an essential element when designing for scenic amenity, beach management and coral restoration.

7.5.3 Restricting User Access

While challenging, restricting user (e.g. community) access to a target reef may be an important management tool. Direct impact on reefs by users such as fishers, octopus hunters, shell collectors and tourists can be substantial, particularly on recolonising corals and when coral abundance is limited. Restricting access requires appropriate education and signage. It also should be enhanced by policy and regulation and requires consistent monitoring and enforcement. Enforcement is critical as a short lapse in this aspect can result in rapid degradation.

Preventing access can be assisted by identifying alternate sites where desired activities can be undertaken, compensating users for any losses that are incurred, and potentially establishing offset sites. Monitoring and reporting on outcomes is essential as it can provide an evidence base for decision makers and enforcement agencies, and can highlight successes to funders and to the local communities.

7.5.4 Collection of New Data and Information

There is a severe shortage of data and information at several locations around the Seychelles. This results in a lack of evidence to support decisions or prioritisation about coral restoration benefits, techniques and applicability. A research program which increases knowledge is an essential element of a broad coral restoration strategy for the Seychelles. Data required include physical dynamics, sediment dynamics, ecological processes and condition. It would also useful to have a better understanding of the socio-economic landscape.

7.5.5 Reduction of Sediment and Nutrient Runoff

Sources of nutrient and sediment entering the marine environment must be identified, and the processes that result in their runoff must be understood. Programs should be put in place to manage the runoff and reduce nutrient and sediment loads. Options include education campaigns, targeted funding of land-based management (sediment traps, wetland construction/restoration, replanting of vegetation etc).

7.5.6 Macroalgal Management

Macroalgae are able to grow at a significantly greater rate than even the fastest growing corals. They are able to colonise bare substrate rapidly and outcompete corals, preventing their colonisation. They are also able to shade young corals, which can result in coral death. Macroalgae management programs can be designed and implemented in which macroalgae are manually removed from surfaces before and during coral restoration activities. It is important that macroalgae are removed from the water. The most cost-effective ways for undertaking these programs is by using volunteer divers. Algae can be removed from the area using bags, but gentle suction pumps which carry algae onto the deck of a boat where algal matter is captured and water is allowed to run-off back into the water is also possible.

7.5.7 Establishing Marine Protected (no-take) Areas

Establishing no-take areas reduces impacts on fish and invertebrate stocks with a resultant improvement in biodiversity and increased abundance of herbivores. This increases the rate of grazing on algae reducing algal biomass and cover. This increases the likelihood of coral settlement, growth of transplanted corals, and the success of coral restoration. Where applicable, marine protected areas should be aimed at protecting the entire seascape in the area (multiple habitats). This will have a positive impact on biodiversity in the area, including important fish species that use multiple habitat types during their lifecycle.

7.5.8 Management of Crown of Thorn Starfish (COTS)

Crown of thorn starfish are voracious predators of coral and when present in large numbers are able to substantially impact coral reefs. In the Seychelles, where coral abundance and biomass are low, the impacts of relatively few COTS can be large. The presence of COTS should be monitored and when they are found, a process should be implemented to remove them. This can be done by euthanising them or collecting them for disposal on land. Removal programs can be implemented working with volunteer divers. Note that the prevalence of COTS can be exacerbated by elevated nutrients.

7.5.9 Managing Long-shore Drift of Sediment

Movement of sand along long beaches, as a result of along shore currents, can have an impact on erosion and accretion. It can have a direct effect on the viability of coral reefs in certain areas where sediment can cover reefs, or where movement of sediment can cause scouring of rocky areas, preventing colonisation of corals. It is important to develop a better understanding of the physical and sedimentary processes at play to enable effective management responses (e.g. groynes) to be designed and implemented. Appropriate design and placement can enable multiple benefits to be achieved, including erosion reduction and increasing suitable habitat for targeted coral restoration.

7.5.10 Education and Awareness

It is essential that stakeholders (local and visitors) are made aware of any coral restoration activities that are being implemented. This includes, guiding them about what they can or cannot do in the vicinity of coral restoration sites; what is actually taking place in each area; and why this is necessary. This can be done through signage, through information provided at tourist accommodation, or through visits or guided tours through restoration exercise. If stakeholders can be supported to buy into the process and develop a sense of custodianship, it is more likely that successful outcomes will be achieved.

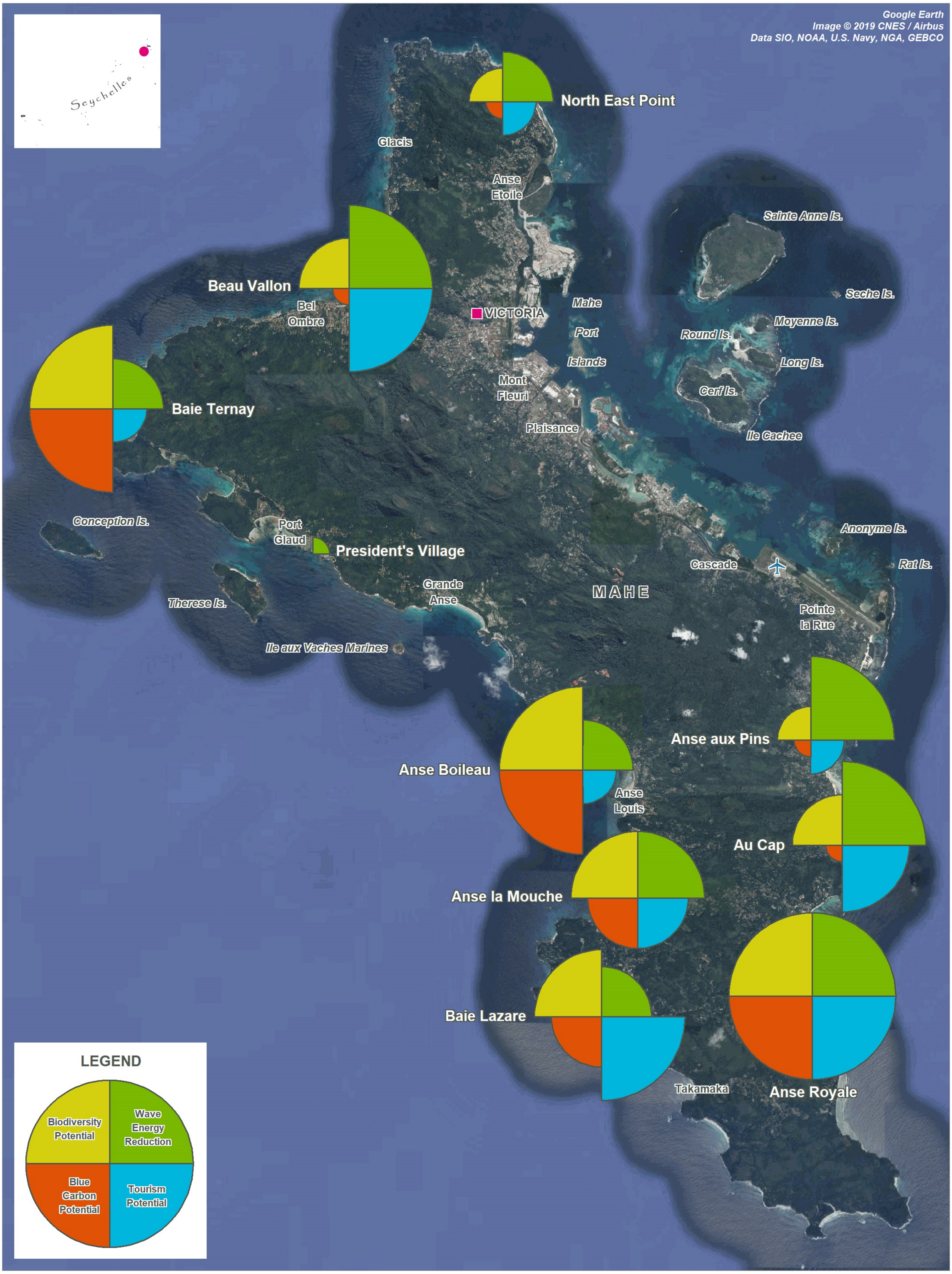
7.5.11 Ecosystem Services

In prioritising sites for coral restoration, we recommend considering the potential for achieving multiple benefits from the restoration activities. To support this, we have summarised the ecosystem services that can potentially be achieved from rehabilitation at each of the high and medium priority sites. Note these are based on available information and further data is required to fine tune these data.

We compare four ecosystem services:

- Biodiversity potential;
- Wave energy reduction potential;
- Tourism potential; and
- Blue carbon potential.

A score ranging from zero to five was used where zero indicates not scored, one shows little potential and five is high potential. Scores were assigned from information and data collated for this report. Note: further research and work is required in some areas to support refinement of the ecosystem services that can be delivered through coral restoration activities.



Title:

Ecosystem Services - Mahe

Figure: **7-2**

Rev: **A**

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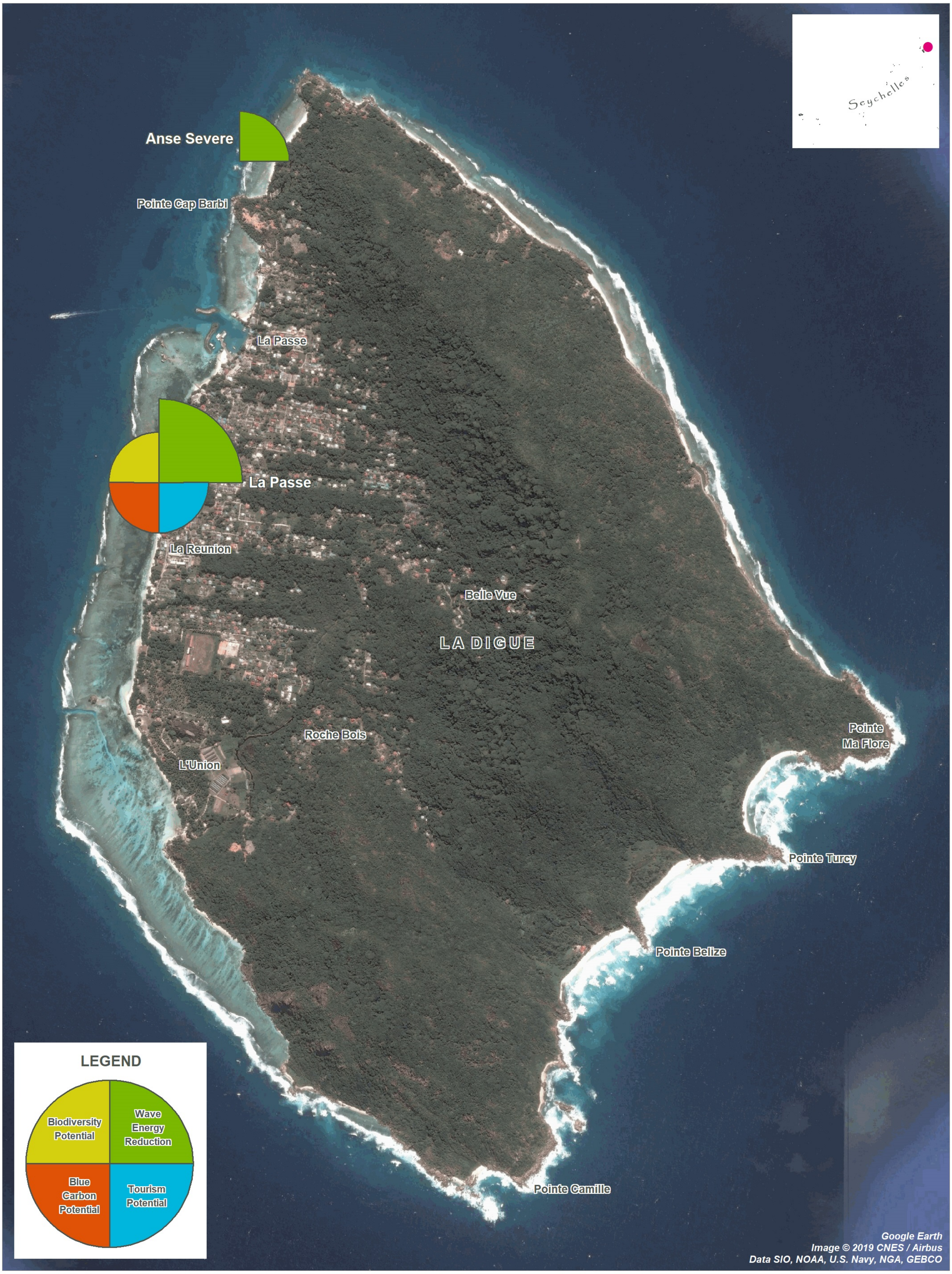

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Ecosystem Services - La Digue	7-3	A

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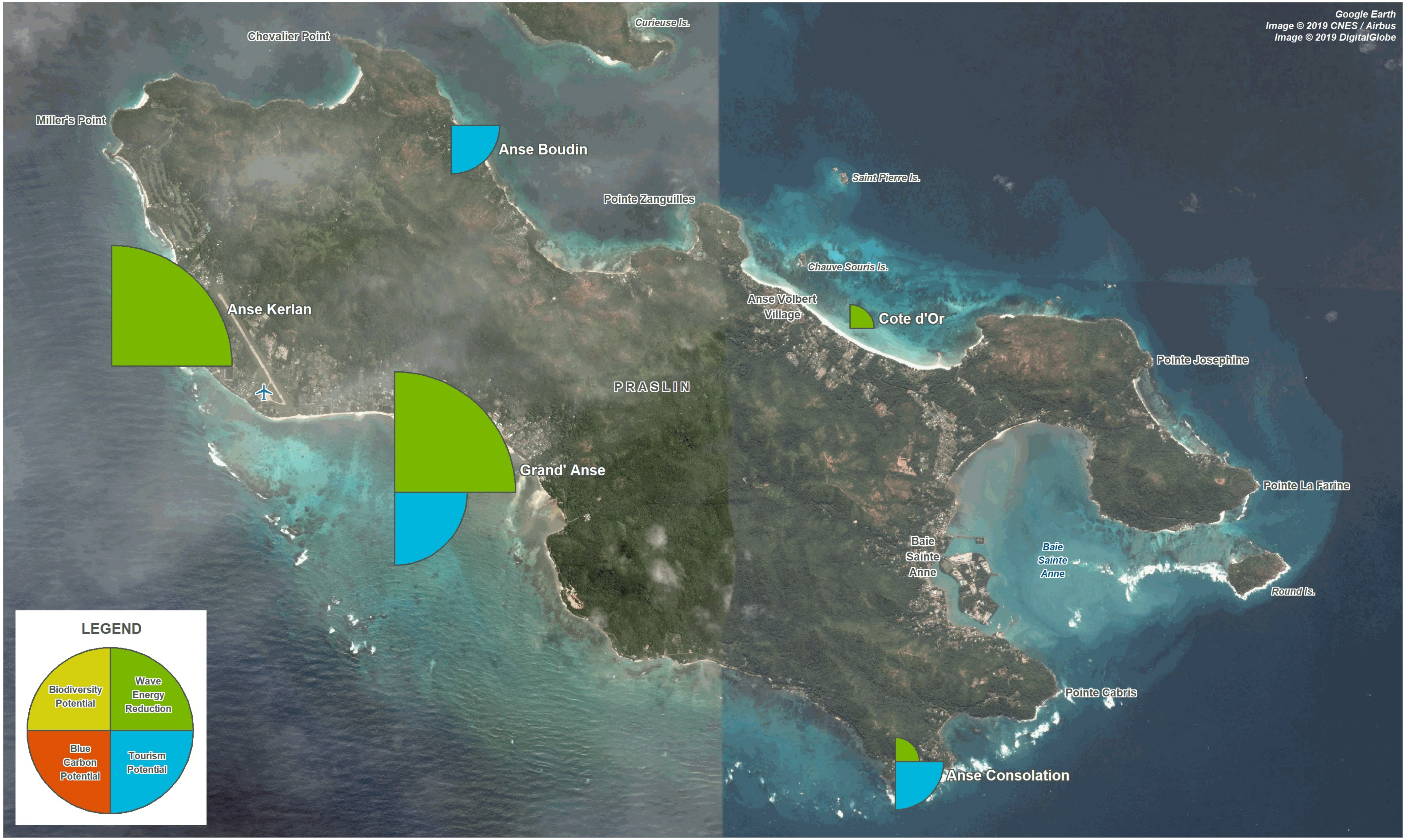

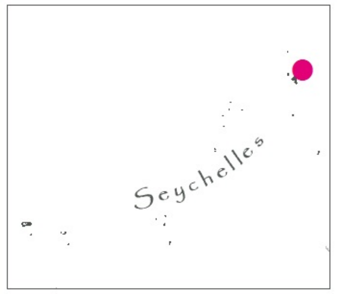

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8 Task 2 Methodology – Economic Evaluation Framework

In order to implement successful coral reef restoration activities within the Seychelles it is necessary to properly evaluate potential sites and project options. The use of an economic evaluation framework is fundamental to understand the relative costs, benefits and risks of undertaking activities to implement coral reef restoration and how different project options compare. The use of an economic evaluation framework allows the funding available for coral reef restoration to be directed to its best use, identify potential private partners to help fund the activities through innovative financing mechanisms, and provide confidence to investors of the type and scale of benefits will be realised.

This section outlines, at a high-level, the best practice approach to undertaking economic evaluation including guidance on achieving high quality outcomes, and common issues. It provides a tailored framework for the economic assessment of coral reef restoration projects that includes common types of costs and benefits, potential values to be used and data sources. It also sets out additional criteria beyond the economic evaluation which will be essential for prioritising investment.

The guidance framework presented in this section of the report supports the current project and provides guidance for future economic assessments of coral reef restoration in the Seychelles. Subsequent sections of this report apply the guidance framework to two study sites in the Seychelles.

8.1 Approach to Economic Evaluation

8.1.1 Cost Benefit Analysis

Cost benefit analysis (CBA) is globally recognised as the recommended approach for assessing the impacts and distributional outcomes of programs and projects and should be used where possible to identify the focus areas and methods for coral reef restoration. CBA is a well-regarded and accepted approach for evaluating the merits of investment options. It has strong theoretical underpinnings in welfare economics and has been applied for more than 80 years across a range of sectors. Despite common misconceptions, CBA is broader than financial analysis – it incorporates all the economic, social and environmental values of importance to various groups in society.

CBA is the preferred approach to economic evaluation of most international organisations, including the World Bank, the OECD and national governments. Best practice guidelines on how to undertake robust cost benefit analysis are provided by the UK Treasury (HM Treasury, 2018), and the OECD (OECD, 2018), and should be referred to in conjunction with the guidance provided in this report. Other approaches to economic evaluation can be undertaken, particularly when limited data is available, however CBA should always be undertaken where practical. Two other potential approaches are described in more detail in Section 9.1.4.

The objective of CBA as an assessment methodology is to highlight to decision-makers whether or not an investment or project proposal has economic merit, and is therefore an important input into decision making processes. CBA is based on the principle that public investment requires demonstration of net benefits to the community as a whole. The benefits of a project may often seem resounding, but they also come at a cost. Undertaking a comparison of the costs and benefits through CBA is important to:

- Demonstrate that the project is improving social welfare or well-being overall;
- Help select projects that present the optimal use of scarce resources;
- Inform who bears the costs of a project or program, and who accrues benefits;
- Help inform and influence decision making; and
- Enable investment outcomes to be communicated to key stakeholders, investors and decision makers.

CBA produces a number of decision criteria that help inform the merits of an investment or selection of a preferred option. The most important output is the net present value (NPV), which is simply the difference between the present value of the benefits and the present value of the costs. A positive NPV indicates that the benefits of an option outweigh the costs, and the investment has economic merit.

There may be occasions when is not possible or feasible to quantify all of the impacts of a project (i.e. such as where there are no, or excessively complex, techniques for monetising the effects of the proposal). In cases where values cannot be quantified it is important to identify and clearly describe the types of benefits and costs a project has on a specific value. This allows project proponents and stakeholders to be informed of all project impacts and make decisions based on the best available information.

8.1.2 Undertaking High Quality Cost Benefit Analysis

The six key steps in undertaking CBA are described in Figure 8-1. These steps must be undertaken in order to develop a robust cost benefit analysis. However, CBAs can be complex, therefore if these steps are not properly applied the analysis may provide incomplete or misleading outputs. In order to undertake a high-quality cost benefit analysis, it is important to also:

- Clearly identify the baseline;
- Undertake distributional analysis;
- Value all relevant economic, social and environmental costs and benefits;
- Clearly attribute the identified costs and benefits to project outcomes; and
- Account for risk and uncertainty.

These are discussed in more detail in the following sections.

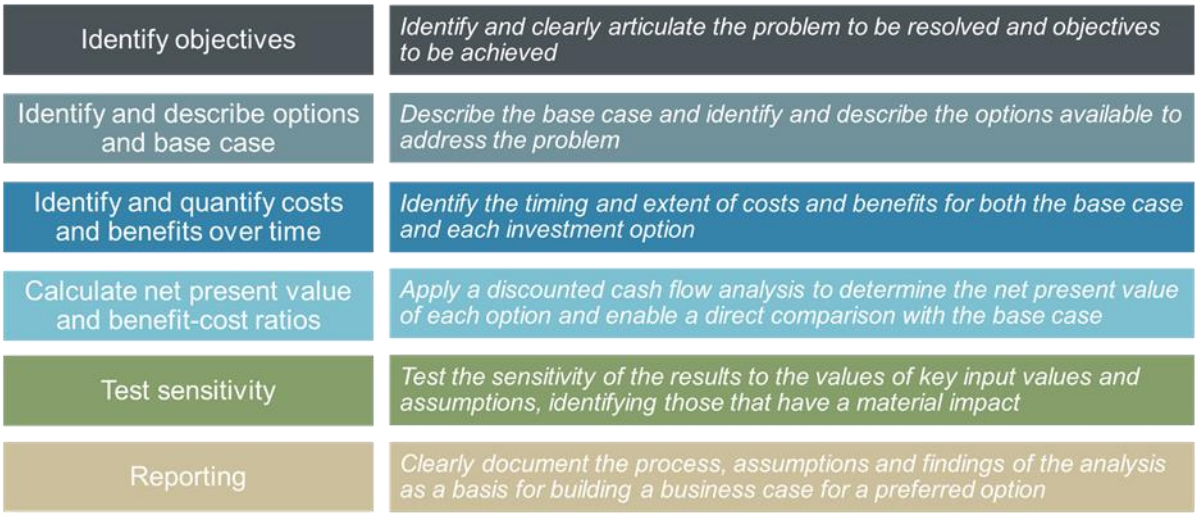


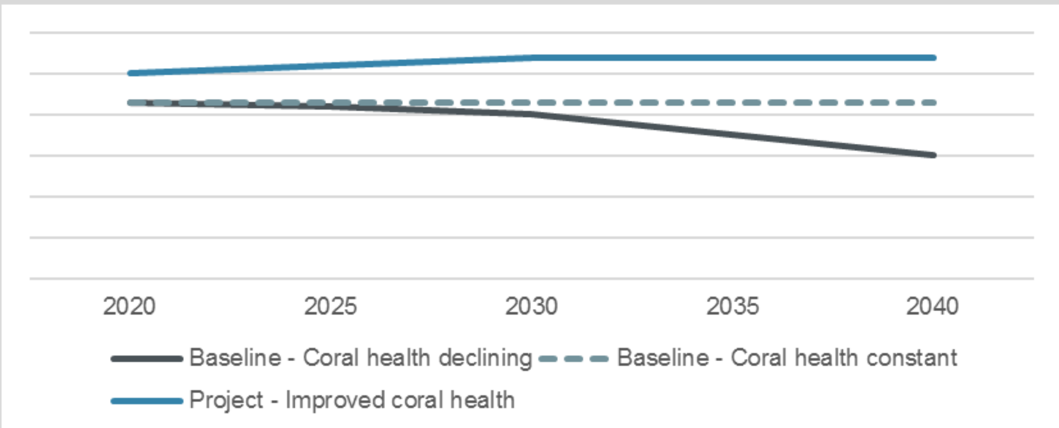
Figure 8-1 Key steps in undertaking cost benefit analysis

8.1.3 Identifying the Baseline

A key feature of CBA is the need to clearly establish a 'base case' scenario, against which other investment options can be assessed. The base case is not necessarily a 'do nothing' scenario, but should reflect the course of action and the associated impacts that would occur in the absence of any alternative investment option. Failure to properly account for changes in the baseline can lead to both over and underestimates of the total costs and benefits of a project. Identification of the baseline may require both physical and socio-economic data, for example expected changes in beach quality without intervention and projected population growth in the area.

Identifying the Baseline – Coral Health

When undertaking a cost benefit analysis of any investment it is important to consider the baseline against which the costs and benefits of the project are to be measured. For example, where a project that leads to increased coral species diversity and abundance, the net change in coral species should be compared not just to the current health of the coral, but to the expected health of the coral over time. If the health of the coral is expected to decline further under current management then the net benefits will be higher compared to if the health of the coral is expected to remain constant.



8.1.4 Distributional Analysis

The key decision metrics of cost benefit analysis show whether a project or proposal is a net economic cost or benefit to society as a whole allowing for an understanding of which project options should be undertaken given limited funding. However often for projects, particularly those using innovative financing mechanisms, it may be more important to understand who bares those costs and benefits, rather than which provides the largest net benefits. Therefore, distributional analysis is extremely important to understand in the context of making an investment decision. An in-depth assessment of project impacts and their distribution will:

- Support stakeholders to better understand the implications of the project across multiple values;
- Provide information to allow the project to be refined and rescoped and enhanced, if required;
- Provide project proponents with the information and confidence they require to make sound investments;
- Allow project proponents to demonstrate the value of the project to stakeholders and the community; and
- Inform potential financing or cost sharing arrangements.

Distributional Analysis – Private vs Public Benefits

Distributional analysis is likely to be of particular importance when considering the potential for private financing options. Two projects may deliver the same net benefits but have different distributional outcomes. For example, for one project the benefits may be widely distributed across the whole population of the Seychelles, equating to a small benefit per person, while the second project has benefits concentrated between a small number of hotels. The second project will be more appropriate for private financing mechanisms, whereas the first project would more appropriately be funded by Government.

8.1.5 Valuing Non-market Benefits

The challenge in application of CBA is that many values, in particular those associated with environmental and social benefits, are difficult to quantify in monetary terms. The value of an economic cost or benefit that is not readily reflected in markets (for example, an improvement in the health of a coral reef) is referred to as a non-market value. Non-market impacts are generally harder to anticipate and quantify and are much more likely to be overlooked. However, economists, particularly environmental economists, have developed and gradually improved a range of valuation techniques for non-market valuation. In many cases, it is possible to draw upon existing studies to identify unit values for particular non-market outcomes and obtain an indication of value.

The Total Economic Value (TEV) framework (illustrated in Figure 8-2) is used to reflect the full range of non-market costs and benefits to the community, accounting for both use values and non-use values.

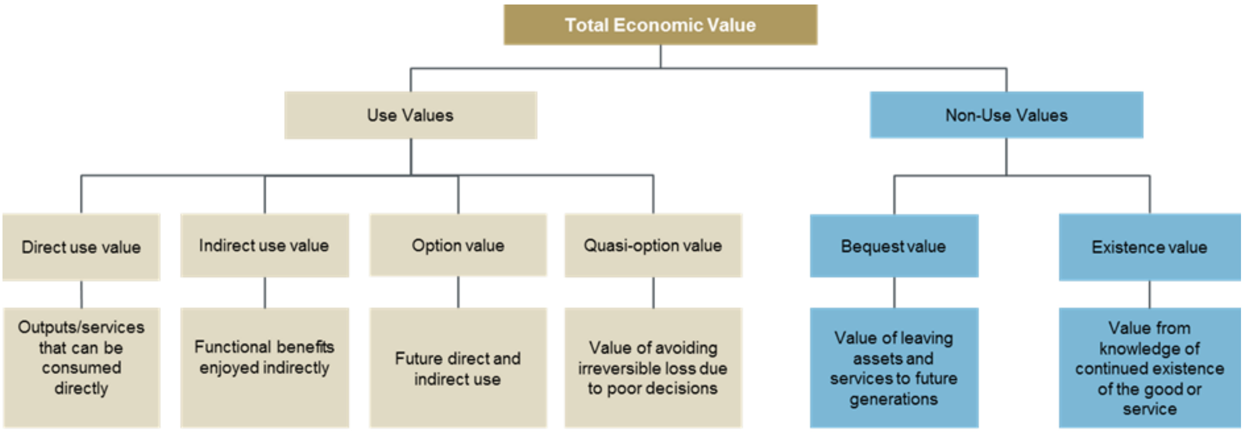


Figure 8-2 Total Economic Value Framework

Two broad approaches to determining non-market values are available: stated preference and revealed preference. Revealed preference methods utilise prices from related services or products to estimate non-market values, while stated preference methods utilise survey methods to outline people's preferences (and willingness to pay) for social and environmental changes. Both methods require significant resources and time to implement, and it is not always possible to adopt these methods in practice.

A common way to overcome these limitations is to use 'benefit transfer'. Benefit transfer in its simplest form uses values calculated for one locality to estimate the values for another (similar) locality. This can be used to leverage previous non-market valuation studies, as well as to substitute for market values where local information is insufficient.

Non-market Values – Divers' willingness to pay for improved reef conditions

When undertaking a cost benefit analysis, there may not always be clear values that can be used to quantify the benefits. For example, a project may improve the health of a coral reef but have limited evidence on the value of a healthy coral reef in the area. One approach can be to use a benefit transfer to estimate value. A study undertaken in Guam assessed divers' willingness to pay for improved reef conditions (Grafeld et al, 2016). The results of this study showed that divers had a mean willingness to pay of $13.48 (2013 $US) for a change in fish biomass from low to high due to improved reef conditions. The results of this, or other studies could be used to calculate the benefits of a project leading to improved reef conditions.

8.1.6 Attributing Costs and Benefits

When undertaking a cost benefit analysis, costs and benefits must be clearly attributed to project outcomes. It is important to consider which costs and benefits would have occurred in the absence of the project, and to understand the net impact of the project options. Analysis should always clearly outline how a project will have an effect on different values. Where there is significant uncertainty around the scale of these effects, sensitivity analysis should be undertaken (see section on accounting for risk).

Attributing Costs and Benefits – Flood Protection

Attribution is particularly important when using cost benefit analysis to support private financing options. It must be accepted by the stakeholders involved that the intervention will deliver the benefits identified. For example, if a hotel is paying for insurance against flooding through investment in coral reef restoration, there must be confidence that the restoration will reduce the cost of dealing with future flooding, and that the future cost of flooding would exceed the current cost of insurance.

8.1.7 Accounting for Risk

The precise value of future costs and benefits is uncertain. It is useful to include a range of results about possible impacts to provide decision makers with adequate information relating to the margin of error surrounding single point estimates of value. This can be achieved by using 'sensitivity analysis', which can help to account for differences in judgement, or uncertainty, and the impacts that they have on the outcomes of cost/benefit assessments. Sensitivity analysis involves altering some of the critical assumptions and recalculating the estimates with different assumptions – for example, 'best case', 'base case' (most likely) and 'worst case' scenarios.

Accounting for Risk – Climate Change

Sensitivity analysis is particularly important in the face of future uncertainty. For example, the outcomes of coral reef restoration may be dependent on future climate change impacts. There may be a risk of future coral bleaching events that will affect the benefits of the restoration projects undertaken. Sensitivity analysis should be undertaken for various climate change scenarios to fully capture the risks of each project. A project that delivers lower net benefits but is less at risk from future bleaching events may be preferable as there is lower risk.

8.1.8 Challenges in Undertaking Cost Benefit Analysis

Undertaking CBA can be straightforward or more complex, depending on the complexity of the problem being assessed. For more complex projects in particular there are common issues that can occur, which those undertaking CBA should be aware of and seek to avoid. These common issues, summarised in Table 8-1, can undermine the robustness of the analysis.

Table 8-1 Common issues in CBA

Common pitfalls	Description
Unanticipated impacts and ignoring non-market impacts	Many potential costs and benefits are unanticipated at the time of project planning. Non-market impacts are generally harder to anticipate and quantify and are much more likely to be overlooked. Nevertheless, listing and estimating all relevant costs and benefits early in the process, as well as all affected parties, should be attempted.
Double counting and miscounting benefits, and optimism bias	Impacts can be doubled counted accidentally. This is usually because they are inherently reflected in the pricing of other benefits (e.g. the benefits from improved recreation and amenity from a beach that is not eroded and resultant higher house prices near the beach – these benefits both represent recreational and amenity benefit, therefore only one should be included). Another serious error is counting costs as benefits. For example, the use of resources such as labour is often counted as an employment

Common pitfalls	Description
	benefit. However, this almost always has a cost (i.e. an opportunity cost) if such resources can be used elsewhere in the economy.
Failure to demonstrate a logical causal relationship between the project and the impacts	Analysis should always clearly outline how a project will have an effect on different values. Impacts for which a causal relationship cannot be demonstrated or assumed with any confidence should not be included in the analysis.

8.1.9 Alternative Approaches to Economic Evaluation

Cost benefit analysis is the preferred economic evaluation method. There are however other methods of analysis that are applied to assess project outcomes when there is limited data available or quantification of benefits and costs is difficult. These include:

- Cost effectiveness and least cost analysis – These methods are partial cost-benefit approaches that compare the relative costs of different options in reference to a specific outcome that has been agreed upon (e.g. reducing beach erosion). A cost-effectiveness analysis expresses the result in terms of the average cost per unit of effectiveness (e.g. the average cost per m^2 of beach protected). While these types of economic evaluation methods are sometimes used when the main benefits cannot be easily valued, they cannot tell you if the preferred option is of net benefit to society. In addition, these evaluation methods cannot be used to find or compare alternative projects that could achieve greater net social benefits by targeting different outcomes. Therefore, these methods should generally only be used where the decision to target a specific outcome has already been agreed upon by decision-makers.
- Multi criteria analysis (MCA) – This form of analysis attempts to compare quantitative and qualitative impacts across different proposals by assigning weights and scores to various criteria that are linked to the objectives of the proposal. MCA ultimately involves some subjective and non-testable judgments on values. In addition, it does not tell the decision-maker whether individual proposals are of net social benefit (i.e. whether anything at all should be chosen), or the optimal scale of any particular proposal. The use of MCA should therefore generally be limited to smaller projects and/or projects where the major benefits cannot be valued or are impractical to value.

8.2 Framework for Evaluation of Coral Reef Restoration Projects

To provide further guidance on undertaking economic evaluation of reef restoration projects a specific framework has been developed. This can be utilised for the assessment of reef restoration projects in the Seychelles and elsewhere. It has been developed through a desktop review of the literature, and tested with the University of Seychelles, and the World Bank. It will be further tested and refined through stakeholder consultation.

The framework identifies the outcomes, benefits, and costs that are most likely to occur when reef restoration is undertaken. It provides a broad approach to steps one to three in the standard cost benefit methodology set out in Section 9.1. It summarises the potential impacts, costs and benefits of undertaking coral reef restoration. It tries to capture the majority of the benefits that may be delivered by these types of projects, however for any individual project there may be other benefits not identified here. For some projects there will also be some benefits or outcomes identified here which are not relevant. The framework is intended to provide a starting point for assessment, which can then be refined in the application to specific projects. The framework is shown in Figure 8-3 and described in more detail below.

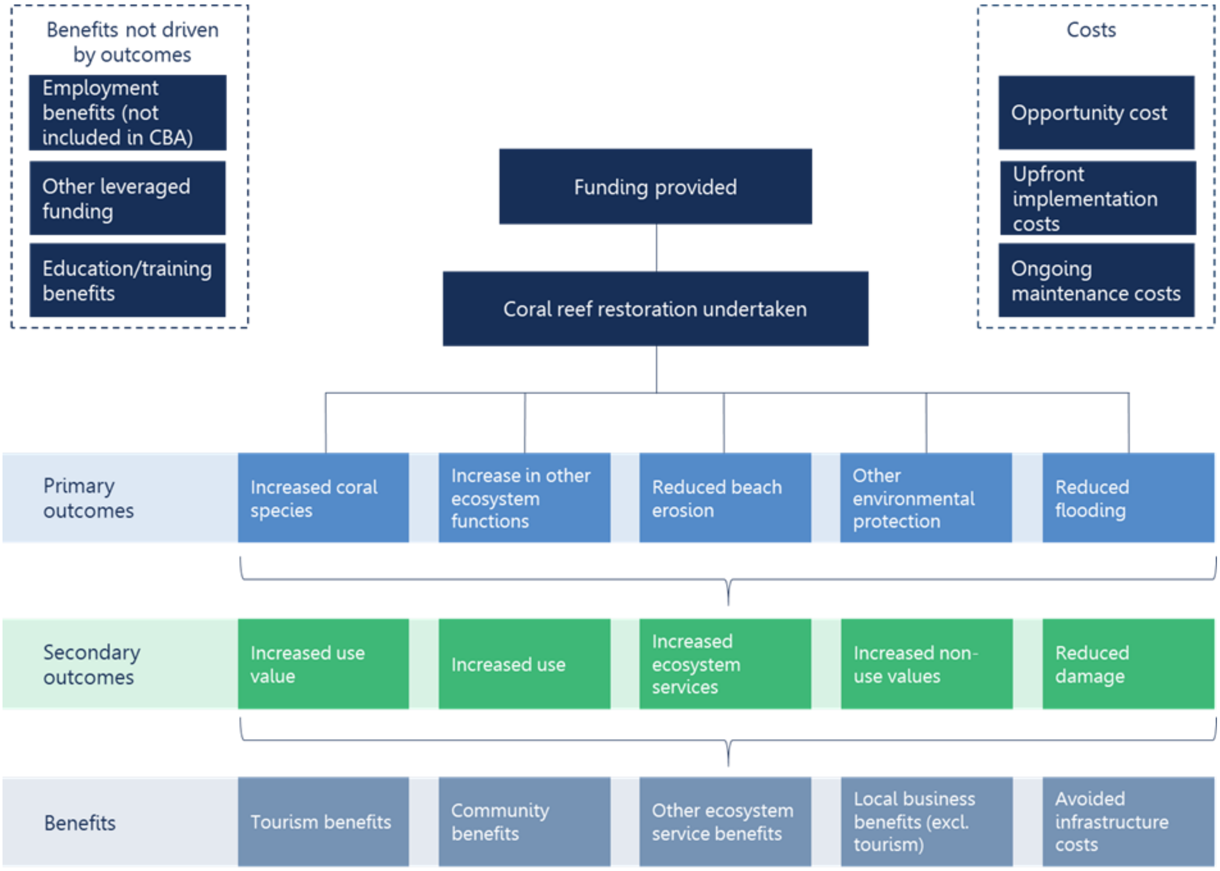


Figure 8-3 Framework for coral reef restoration

8.2.1 Primary Outcomes

The primary outcomes of coral reef restoration include the outcomes for the reef itself such as increased coral and other marine species, and the outcomes for the assets the reef protects. This includes beaches, seagrasses and mangroves, and artificial assets such as residential and commercial properties and infrastructure.

- Increased coral species (diversity and abundance): A key outcome will be increased coral present on the reef. This may be an increase in both abundance and diversity, depending on the type of restoration undertaken, and recovery of ecosystem processes including coral recruitment. There may also be increases in structural complexity of the reef, and improved genetic repositories and connectivity between reefs.
- Increase in other ecosystem functions and processes: Another direct outcome is likely to be an increase in biomass in other marine species such as fish and invertebrates. This may lag the reef restoration by some years, and the impact on diversity and abundance may vary significantly by location and approach to restoration.

- Reduced beach erosion: Increased coral reef cover helps to provide additional protection from sediment erosion from local beaches. Again, this outcome is likely to be highly dependent on the location and type of restoration undertaken.
- Reduced flooding: The presence of coral reefs also provides protection from flooding, reducing the height of flood events. Again, this outcome will be highly location dependent.
- Other environmental protection (e.g. seagrass and mangroves): The coral reef restoration may also protect other ecosystems such as seagrass, mangroves and wetlands.

8.2.2 Secondary Outcomes

Secondary outcomes are dependent on the successful achievement of the primary outcomes of coral reef restoration. These secondary outcomes are key to the delivery of benefits associated with restoration.

- Increased recreational value and use: Increased diversity and abundance of both coral and non-coral species is expected to increase the recreational value of the reefs, with visitors placing a higher value on healthy reefs than unhealthy reefs. Similarly, reduced beach erosion will increase the recreation value of the beaches as visitors will place a greater value on visiting non-eroded beaches. There are expected to be higher visitor numbers to the healthy reefs than the non-healthy reefs and to the better-quality beaches.
- Increased ecosystem services (e.g. increased carbon sequestration): The healthy reefs will provide increased ecosystem services, including provisioning services such as increased fish stocks. The protection of other environmental assets such as seagrass or mangroves will also result in an increase in regulating services, such as carbon sequestration.
- Reduced damage: By reducing flooding, the healthy reefs will help to reduce the damage done to buildings and infrastructure during flood events.
- Increased non-use value: The presence of healthy reefs and higher quality beaches is also likely to lead to higher non-use values. Healthy reefs and higher quality beaches might be valued just for their existence (people like knowing the coral reefs are healthy even if they do not visit them), or through altruism (people like knowing coral reefs are there for others or for future generations). These values may also be related to cultural or heritage values around the beaches and reefs.

8.2.3 Benefits

Benefits are dependent on the successful achievement of the primary and secondary outcomes of coral reef restoration.

- Tourism benefits: Tourism benefits are delivered through increased visitation, generating benefits for local tourism businesses such as hotels, restaurants and tour operators. Increased visitation may arise from increased recreational value and use outcomes, but may also be due to reduced interruptions to visitation due to flooding.
- Community benefits: Community benefits include direct benefits to local residents due to increased recreational value and use of the reef, increased fish or shellfish catch for food consumption, and from reduced damage to property due to reduced flooding. Community benefits

also include increased non-use benefits for the local population such as described above, and include cultural and heritage benefits.

- Local business benefits (non-tourism related): Other than tourism businesses, other local businesses may also benefit from the coral reef restoration. Commercial fishing may see benefits due to increased fish abundance, similarly there may be increased opportunities to develop businesses related directly to reef restoration.
- Other ecosystem service benefits (e.g. value of carbon sequestered): As well as direct ecosystem service benefits such as increased fish catch, there will be indirect benefits delivered by increased regulating services, such as carbon sequestration.
- Avoided infrastructure costs: As well as reducing the cost related to flooding in the short term, there are also potential benefits due to being able to delay other flood defence works, such as seawalls.

8.2.4 Other benefits

There are also potential benefits related directly to undertaking the reef restoration, regardless of whether the intended outcomes are achieved.

- Employment benefits (not included in CBA): There may be increased employment opportunities related to coral reef restoration, however these will not be included in the cost benefit analysis.
- Educational/training benefits: Where local residents receive training in coral reef restoration techniques there will be benefits relating to improved skills and capability of local residents.
- Other funding: Where coral reef restoration projects are able to leverage funding from international sources, this will be a net benefit for the Seychelles.

8.2.5 Costs

The costs of reef restoration include both direct implementation and management costs, and opportunity costs from undertaking reef restoration.

- Upfront implementation costs: These costs include upfront capital and other costs which vary depending upon the type, location and scale of intervention as well as other factors. For example, the intervention may include coral planting or a new artificial reef structure. The delivery of the outcomes and benefits outlined above will vary according to the intervention deployed.
- Ongoing costs: These costs include the ongoing costs required to maintain and manage the intervention. They could include the cost of 'coral gardening', for example, or other ongoing management costs.
- Opportunity cost: Opportunity costs include the impact the coral reef restoration intervention may have on other activities. For example, fishing and boats may be restricted on the coral reef restoration area for a period of time, or permanently. This will result in the loss of the benefits from that activity. It is important to the note that a comparison between the coral reef restoration project and an alternative activity, such as the development of a new aquaculture facility in the same area

(assuming they can't both occur), would require a separate CBA for each activity order to compare the net benefits of each.

8.2.6 Data

In order to apply this framework data gathering is essential. This requires data on the direct outcomes of the projects, for example, change in biodiversity and data on the benefits, for example growth in tourism. The level of data required depends on the scale and expected impact of the project. The time and effort invested in a cost benefit analysis, including gathering non-market data and values, should be proportional to the scale of investment or scale of project impacts. To provide guidance on the level of data that may be required a 'request for information' (RFI) has been developed that can be used in future to easily identify the data requirements for the cost benefit analysis (Appendix B).

As discussed in Section 9.1, there are often challenges in the application of CBA to environmental outcomes due to limited evidence on the economic value of environmental benefits. This is likely to be a challenge for future assessment of reef restoration projects in the Seychelles, in particular where there is limited time or funding to assess specific environmental values. However, there are a range of studies from the literature that are appropriate for use in benefit transfer for future assessment of coral reef restoration in the Seychelles. A comprehensive literature review has been undertaken of potential non-market values to be used in cost benefit analysis of coral reef restoration. A full table of values has been provided in Appendix C.

8.2.7 Additional Evaluation Criteria

When evaluating potential projects and proposals for coral reef restoration there are other considerations beyond the evaluation of costs, benefits and distributional impacts. We have therefore developed a list of key evaluation criteria to be used to assess the suitability of coral reef restoration activities in the Seychelles and whether, for the purposes of this project, a proposed study site is both suitable and feasible as a case study.

The evaluation criteria are indicative, recognising that there may be additional preferences of stakeholders or that one of the factors may hold a greater importance over another (the evaluation criteria are not weighted). Therefore, these criteria may be adjusted when undertaking future evaluations. The evaluation criteria used are summarised in Figure 8-4 and include:

- Technical feasibility: is coral reef restoration constrained?
- Outcomes: what are the key primary outcomes of the coral reef restoration?
- Benefits: what is the scale of benefits expected and how are they distributed? Is attribution clear?
- Policy alignment: does the project align with strategic policy objectives (e.g. Seychelles' Blue Economy Roadmap)?
- Data availability: how available and what quality is the data and information needed to complete the economic evaluation?
- Financing options: how likely is the project to be funded through private financing (see Appendix C).
- Scalability: how likely is it that the approach can be scaled to other parts of the Seychelles?

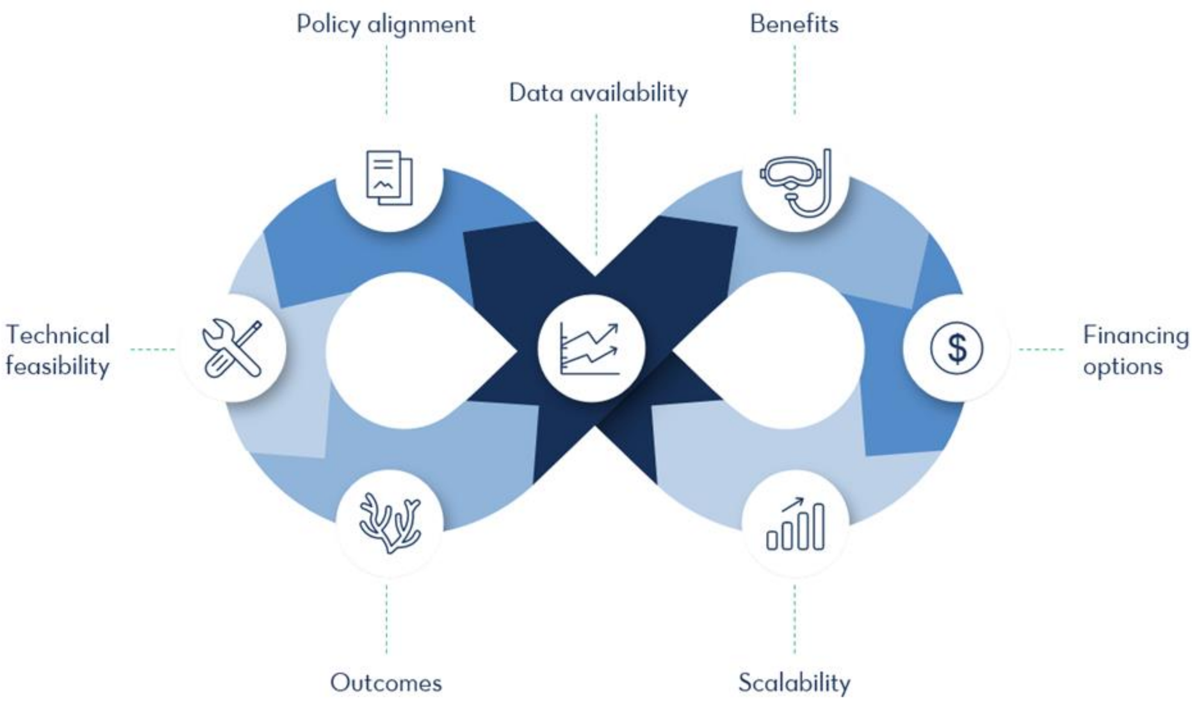


Figure 8-4 Summary of evaluation criteria for the case study site selection

9 Application of Economic Assessment Methodology to La Digue and Au Cap

9.1 Introduction

The economic assessment methodology was applied to two study sites in the Seychelles: La Passe (La Digue) and Au Cap (Mahé). The model was populated using a desktop analysis of likely benefits, based on prior studies and reports, and the outputs from our field investigation.

Data on the primary and secondary outcomes was gathered through the field work of the two sites. An initial desktop review and information gap analysis provided data on potential benefits and values to be used in benefit transfer, but identified that further detailed data for each case study site was required. A request for information (RFI) was provided to various parties in the Seychelles to gather more direct data on the two sites. The RFI also includes detail on the expected costs of implementing different restoration techniques.

The assessment of the two study sites was undertaken using the guidance framework. The expected primary and secondary outcomes of coral reef restoration at the two study sites were assessed using the results of the field work in Task 1 and other relevant data sources. The likely scale and importance of benefits has then been identified, again with reference to the results of Task 1, the wider literature and an assessment of the potential values to be used in benefit transfer. An MCA was then undertaken for three potential options for coral reef restoration. The criteria for the analysis were based on the identified benefits, and the weightings used in the MCA for each criteria was based on the assessment of the scale and importance of the different benefits to each site. This provided an early stage assessment of the two sites, and the potential options which could be undertaken. Following this a case study was selected from the two study sites for further and more detailed analysis. This enabled a detailed business case for one of the two study sites can be developed.

9.2 La Passe (La Digue)

9.2.1 Overview of Area Assessed for the Economic Evaluation

The economic analysis examined the assets along the populated areas of the western coastline of La Digue, including La Passe. This area comprises the primary area of economic activity on the island and includes a range of environmental, social and economic assets.

- Hotels, private residences, cafes and restaurants;
- Hospitals, marina and roads;
- Extensive sandy beaches and lagoons;
- Large areas of seagrass and areas of coastal mangroves to the south of La Passe; and
- Limited agricultural land.

Coral reef on the western coastline provides protection for these assets as well as being an attraction for tourists and locals.

9.2.2 Reef Condition Assessment

The reef condition is considered to be poor, with very low live coral cover compared to other species and large areas of rubble and bare rock. There was little evidence of any recently dead coral at the two sites, suggesting that the lack of coral is likely to be due to historic bleaching events rather than more recent events. It therefore appears there has been a lack of response following the significant bleaching events which have occurred in the past.

Primary and Secondary Outcomes

A high-level summary of the baseline condition of the primary and secondary outcomes using the cost benefit analysis framework presented in Section 8 is provided in Table 9-1. The focus is understanding the likely baseline, as identified through the current work program, from which the potential impact of any intervention can be assessed.

Table 9-1 Summary of coral reef restoration outcomes

	Description
Primary outcomes	
Increased coral species (diversity and abundance)	• Low level of existing coral species, with the area predominantly rubble and bare rock. • It is technically feasible that live coral is used as a restoration option in La Passe however this is expected to be limited to the slope of the reef, not the reef flat. Whether this is an appropriate technique will depend upon a range of criteria, including whether there are likely to be significant tourism (or other) benefits for reef restoration using live coral.
Increase in other ecosystem functions	• Low levels of fish biomass identified on the reef, whilst sea urchins abundant. • High potential for coral reef restoration to attract additional fish biomass, if an appropriate restoration method is applied.
Reduced beach erosion	• High risk of beach erosion identified in the La Passe area, with evidence of existing coastal erosion being substantive. • The loss of the reef is likely to increase the risk of beach erosion.
Reduced flooding	• High risk of flooding identified in the La Passe area due to extreme weather. • The loss of the reef is likely to increase the risk of flood vulnerability.
Other environmental protection (e.g. seagrass and mangroves)	• The reef currently provides protection to an extensive area of seagrass and limited areas of mangroves and other stabilising vegetation on the shoreline. • The loss of the reef is likely to result in the loss of these environmental assets.
• **Secondary outcomes**	
Increased recreational value and use	• The area is used extensively for beach recreation (being a key attraction to the area for tourists), kayaking and other activities. However, there is limited dive and snorkelling activities with the diving industry in decline.
Increased ecosystem services (e.g. increased carbon sequestration)	• Seagrass protected by the reef provides carbon sequestration services. • The reef does not provide high-levels of provisioning services for fish and other marine life, evidenced by low levels of biomass.
Reduced damage	• The reef helps to reduce damage to private homes, hotels, businesses (cafes, restaurants, limited agriculture), economic infrastructure (roads, marina) and social infrastructure (e.g. Logan Hospital) from extreme flood events, however La Passe remains vulnerable to flood during extreme weather.
Increased non-use value	• No clear evidence identified. A survey undertaken by Goizueta (2018) with local businesses identified they were aware of the importance of the reef and its poor state.

Costs

Potential costs associated with reef restoration are extremely variable and depend upon the chosen restoration technique. Five different techniques were examined in Section 5. Of the five techniques, artificial reefs are likely to have the highest upfront implementation costs (including labour and materials for the artificial reef structures) however the intensive and expensive planning and deployment can be offset by relatively easy and inexpensive management because of natural recruitment and reproduction of corals. Coral gardening, transplantation and microfragmentation will have lower upfront implementation cost than an artificial reef but there will be a higher implementation costs in the form of transplantation and gardening. Other methods, such as larval restoration and the management of external impacts, have lower upfront and implementation costs however may provide greater levels of implementation risk. All potential reef restoration options are viable in La Passe. However, restoration using live corals is likely to be limited to the reef shoulder and not the reef flat.

Exact costs of reef restoration are dependent upon several factors, for example reef accessibility and availability of the required facilities to provide the restoration option. However, an estimated average cost of $US20.94 for each colony survivor of larval restoration, compares favourably to land based coral nurseries which can cost up to $US325 for coral colonies, and sits competitively against coral transplantation which can cost $US13 per coral colony.

The type of reef restoration action may also have opportunity costs. For example, the Seychelles' Blue Economy Roadmap 2018 – 2030 outlines range of activities, such as the development of aquaculture, that may be prevented if coral reef restoration is implemented. While there are no known plans for aquaculture at La Passe, undertaking coral reef restoration activities may limit development of aquaculture in future due to concerns over pollution and habitat degradation for the reef. In addition, successful implementation of coral reef restoration may be further dependent upon limiting implementation risks such as fishing activity and tourism if there is a risk of trampling during snorkelling/diving/recreational activities. In La Passe, the reef appears to be affected by human activity including fishing and other recreational activities that cause damage to the reef (e.g. trampling). Successful implementation of coral reef restoration may be dependent upon limiting these activities from occurring through complimentary management activities.

9.2.3 Summary of Benefits

A number of potential benefits can be identified for La Passe through the implementation of coral reef restoration. A brief description of the likely benefits is provided in Table 9-2, based on the outcomes identified through Task 1 and using values identified through desktop research. These benefits have been identified at a high level at this stage of the assessment. A more detailed CBA would require further clarity on the extent to which benefits can be attributed to individual project outcomes.

The guidance framework in Section 8 identified several additional benefits to those described in Table 9-2. The 'other benefits' include employment benefits, education/training benefits and other funding provided. The benefits are important to consider as part of the overall evaluation.

Table 9-2 Overview of expected benefits of coral reef restoration in La Passe

<table>
<tr><th></th><th>Description</th></tr>
<tr><td colspan="2">Benefits</td></tr>
<tr><td>Tourism benefits</td><td>Tourism benefits are likely to accrue in La Passe as a result of coral reef restoration. The key drivers of tourism benefits include:
• Increased visitation and beach use value for tourists due to reduced erosion, and reduced need for protective infrastructure in the future. Research by Phillips (2011) showed that significant value is placed on beaches without man made protection infrastructure such as groynes or sea walls, which is predominantly the case in La Passe.
• Potential for increased snorkelling, diving and fishing recreation from tourists due to increases in live coral and other marine biomass, which is currently limited in La Passe but has been demonstrated to have a high value in other studies. Goizueta (2018) indicates that tourists currently chose to visit La Digue for reasons other than these recreational activities, such as beaches, bike tours or ‘creole vibe’, improved reef health may increase the numbers visiting specifically to undertake recreational activities associated with the reef. Diving and snorkelling may also see increases due to the actual activity of coral reef restoration as has been demonstrated in other areas in the Seychelles.
• There are also potential benefits delivered by reduced damage from flooding which would otherwise negatively affect the tourism industry in La Passe. For example, the CZMU (2018) identified 8 hotels in La Passe that are likely to be 1 in 25-year floods, which would affect tourism in the area.
The island of La Digue is visited by significant numbers of tourists each year, therefore these benefits are likely to be highly important to the overall value of the coral reef restoration projects. Previous research by Cesar et al. (2004) suggested that the annual recreational value of snorkelers in La Digue in 2005 was approximately $7.5 million ($US 2005) based on a WTP survey.
Research in St Vincent and the Grenadines (Christie et al, 2015) showed that tourists were willing to pay $88.48 per household per year to improve six ecosystem services including; fishing, coastal protection, human health, ecosystem resilience, beach recreation, and diving/snorkelling.</td></tr>
<tr><td>Community benefits</td><td>Community benefits are also likely to occur in La Passe as a result of the coral reef restoration activities. The key drivers for community benefits include:
• Increased visitation and use value of the beach for local residents as described above.
• Increased visitation and recreation value from snorkelling, diving and fishing for local residents as described above.
• Reduced flood damage costs to private property in the area, or reduced expenditure on private flood protection.
• Increased non-use value of the coral reef due to existence, bequest and cultural values.
These benefits on a per person basis may be relatively high, for example the study in St Vincent and the Grenadines discussed above found that locals had a WTP of $54.41 for improvement in six ecosystem service benefits. However, the local population is relatively small with 2,800 people in the whole of La Digue, concentrated around La Passe.</td></tr>
</table>

	Description
	Therefore, these benefits may be of lower total value than the tourism benefits identified above. This is shown in Cesar et al. (2004) which suggests the annual recreational value of snorkelling to local residents in La Digue in 2005 was approximately $1 million, compared to $7.5million for tourists ($US 2005).
Local business benefits (non-tourism related)	Local business benefits in this area may include: • Artisanal fishing is of paramount importance to the Seychellois. It is largely limited to the Mahé Plateau that comprises the islands of Mahé, Praslin, and La Digue. The plateau is fished by 140 whaler- and schooner-type vessels and at least 400 outboard motor vessels, as well as sport and recreational fishing boats. The total annual landed catch amounts to more than 4,000 tons, valued at around $US12.5 million and supplies most of the domestic market (World Bank, 2017). The volume and value of fish catch may be increased due to reef restoration creating value for local businesses both directly and indirectly involved in artisanal fishing. • Depending upon the coral reef restoration type and business model, it may be possible that a local business is established to undertake coral reef propagation and gardening or other activities associated with reef restoration. Currently, these types of business activities occur on other islands such as Mahé. Research by Cesar et al (2004) suggests that the increase in the annual value of fisheries in La Digue due to increased fish catch would be approximately $36,000 ($US 2005).
Other ecosystem service benefits (e.g. value of carbon sequestered)	Other ecosystem services identified around La Passe include carbon sequestration within seagrass beds and coastal stabilisation due to mangroves and other fringing vegetation. Depending on the extent to which reef restoration protects these ecosystems there will be benefits due to an increase or prevented decline in these services.
Avoided infrastructure costs	There are likely to be improved beach protection outcomes due to coral reef restoration. In La Passe this would reduce the cost of implementing new beach or flood protection measures such as sea walls or groynes, or replacement of damaged infrastructure (e.g. roads and hospitals) due to flooding. The CZMU (2018) shows that approximately 10 km of roads as well as the hospital and community centre are within the area affected by 1-in-25-year flood events.

9.2.4 Results of Multi-criteria Analysis

A desktop multi-criteria analysis (MCA) was undertaken for La Passe to support the economic evaluation. This approach can be useful to inform which benefits may be of greatest importance for each site, as well as providing an understanding of the trade-offs between different options. Three possible options for coral reef restoration were used to inform the MCA, which can then highlight the different types of benefits possible. The three options were:

- Option 1: Artificial reef sited to reduce wave runup – involves developing and deploying new artificial structures to provide protection from flooding and erosion.
- Option 2: Artificial reef with coral gardening sited to support coral growth – involves developing and deploying new artificial structures with additional provision of live coral on new substrate.

- Option 3: Coral Gardening, Transplantation and Microfragmentation – involves the provision of live coral on existing substrate.

All three options were assessed relative to a “no action” scenario, whereby no coral reef restoration activities are undertaken meaning that the results show the ‘delta’ of each of the three options assessed (i.e. a “no action” option would measure as a zero against each of the benefit types in Table 9-3). The results of the desktop MCA are presented in Table 9-3.

Table 9-3 Summary of results from multi-criteria analysis

Benefit type	Weighting	Option 1	Option 2	Option 3
Benefits				
Tourism benefits including benefits for businesses	40%	2	4	3
Community benefits including coastal resilience	20%	2	4	3
Local business benefits (non-tourism related)	5%	1	4	4
Other ecosystem service benefits	5%	4	3	2
Avoided infrastructure costs	30%	4	3	2
FINAL SCORE (weighted total)		**2.65**	**3.65**	**2.7**
Costs				
Upfront expenditure		High	Medium	Medium
Ongoing maintenance		Low	High	High
Opportunity costs		Low	Medium	High
Risks				
		Low	Medium	High

The value of the benefits assessed through the MCA are related to both the description of the benefits provided in Table 9-2, and to the specific reef restoration options described above. The weightings given to each benefit are based on the expected scale of the benefits and likelihood of being achieved. These weightings have been tested with the project team in the Seychelles. The rationale for the values assigned for each option are:

- Tourism benefits – tourism benefits are related to the presence of coral and other marine species but also to beach condition and flooding. Option 1 provides limited expected improvement in coral condition or marine diversity but reduces the risk of beach erosion and flooding. Option 2 also reduces the risk of beach erosion and flooding, although to a lesser extent, with greater potential for improvements in coral and marine biomass. Option 3 provides a much greater potential for live coral and increased marine biomass and diversity, however it is likely to take much longer to provide protection against beach erosion or flooding.
- Community benefits – these are expected to be affected in the same way as described for tourism benefits.

- Local business benefits (non-tourism related) – these benefits are related to fishing and the presence of industries related to reef restoration. These benefits are likely to be most significant under Options 2 and 3.
- Other ecosystem service benefits – these benefits are directly related to the protection provided by the reef structures to other ecosystems such as seagrass and mangroves. As discussed in relation to beach erosion, Option 1 is most likely to generate these benefits, particularly in the short-term as Option 3 is constrained to the reef shoulder not the reef flat.
- Avoided infrastructure costs – again these benefits are related to beach erosion and flooding, with Option 1 most likely to deliver these benefits.
- Costs – the relative costs of each type of reef restoration have initially been based on the cost information (where available) provided in Appendix A.
- Risks – Option 1 is expected to have lower risks associated with it as the outcomes are based on reduced beach erosion and flooding using an engineered artificial structure. Option 3 faces the highest risks as the outcomes are dependent on successful coral propagation which will take longer to generate benefits. There are also risks associated with the management practices required to successfully undertake live coral provision, including banning access to the reef for recreational activities, which would significantly decrease the benefits of this option.

9.2.5 Conclusions

The desktop economic analysis of La Passe has highlighted that coral reef restoration can provide several important economic benefits. The benefits which are likely to deliver the highest value in La Passe are:

- Tourism benefits: tourism benefits are likely to be high. Tourism benefits will be provided if the coral reef restoration protects the beaches in La Passe, which are a key asset that currently draws tourists to the island. New tourism will also be established if the coral reef restoration technique involves an increase in live coral and increases fish and other marine biomass.
- Avoided infrastructure costs: coral reef restoration can also offset future infrastructure requirements to protect the coast from erosion.

The rapid MCA assessment demonstrates that Option 2 is the most likely to deliver the highest benefits. This is due to the potentially high values placed on the presence of live coral and marine biodiversity by both tourists and local residents, as demonstrated in other areas. However, this option presents higher ongoing costs and more risks than Option 1, which still delivers benefits in terms of reduced beach erosion, flood protection and protection of other ecosystems.

The three reef restoration options are potentially suitable for a number of different financing mechanisms. At a high level, Options 2 and 3 may be suitable for a tourism tax approach (e.g. tourism-based user fee or voluntary surcharge program), given the majority of the benefits are delivered through recreational use of the coral reef itself whether through diving, snorkelling or fishing. Option 1 may be more suitable for a financing mechanism that generates cash flow due to the benefits of reduced beach erosion and flood protection which will accrue to hotels and tourist operators in the area (e.g. insurance or income from commercial activities).

9.3 Au Cap

9.3.1 Overview of Study Site Assessed for the Economic Evaluation

The economic analysis examined the assets along the populated areas of the western coastline Mahé in the Au Cap region. This area comprises significant economic activity on the island, however is significantly smaller than neighbouring city of Victoria (the capital of the Seychelles). There are also several other settlements on Mahé, concentrated in the coastal plains surrounding the island. The area of study in this project includes a range of environmental, social and economic assets, including:

- Hotels, retail areas, private residences, cafes and restaurants;
- School, golf course, roads and the eastern extent of the Seychelles airport in the north of the study area;
- Extensive sandy beaches and lagoons;
- Evidence of seagrass beds; and
- Small areas used for agriculture.

Coral reef on the eastern coastline provides protection for these assets as well as being an attraction for tourists and locals alike.

9.3.2 Conclusion of Au Cap:

The profile of the reef at Au Cap is similar to that found at La Passe. The reef condition is considered to be poor, with very low live coral cover compared to other species and large areas of rubble and bare rock. The potential for coral reef restoration is considered to be technically feasible however there appears little opportunity for reef restoration through live corals.

Primary and Secondary Outcomes

A high-level summary of the baseline condition of the primary and secondary outcomes using the cost benefit analysis framework is presented in Table 9-4.

Table 9-4 Summary of coral reef restoration outcomes

	Description
Primary outcomes	
Increased coral species (diversity and abundance)	• Low level of existing coral species, with the area predominantly rubble and bare rock. Any live coral found was overgrown with algae. Little coral recruitment is likely to be occurring. • Restoration techniques are not expected to include live corals or enhance coral recruitment.
Increase in other ecosystem functions	• Evidence of existing biomass identified on the reef, including fish and sea urchins, however impacts of fishing and trapping are evident. • High potential for coral reef restoration to attract additional fish biomass, if an appropriate restoration method is applied.

	Description
Reduced beach erosion	• High risk of beach erosion identified in the Au Cap area, with evidence of existing coastal erosion being substantive. • The loss of the reef is likely to increase the risk of beach erosion.
Reduced flooding	• High risk of flooding identified in the Au Cap area due to extreme weather. • The loss of the reef is likely to increase the risk of flood vulnerability.
Other environmental protection (e.g. seagrass and mangroves)	• The reef currently provides protection to a limited area of macroalgae and limited seagrass as well as limited areas of mangroves and other stabilising vegetation on the shoreline. • The loss of the reef is likely to result in the loss of these environmental assets.
Secondary outcomes	
Increased recreational value and use	• The area is used for recreational fishing (boats and traps), beach recreation and related other activities. However, there is limited dive and snorkelling activities and the area is not known to have a large tourism industry (compared to other areas of Mahé and other islands).
Increased ecosystem services (e.g. increased carbon sequestration)	• Macroalgae that is protected by the reef provides carbon sequestration services. The reef provides provisioning services for fish and other marine life (e.g. octopus), as evidenced by biomass currently present.
Reduced damage	• Reef helps to reduce damage to private homes, hotels, businesses (cafes, restaurants, limited agriculture), economic infrastructure (roads, marina) and social infrastructure due to extreme flood events, however Au Cap remains vulnerable to flood during extreme weather. • Au Cap has extensive concrete sea wall that also contributes significantly to reduced damage.
Increased non-use value	• No clear evidence identified.

Costs

Potential costs associated with reef restoration are expected to be similar to those presented for La Passe. However, there appears little option at Au Cap to implement direct live coral gardening, transplantation and microfragmentation as well as other methods relying in coral recruitment, such as larval restoration. Consequently, options for implementing coral reef restoration at Au Cap are more likely limited to those that include subsurface structures to be put in place, such as artificial reefs, which tend to have higher upfront implementation costs.

Au Cap also appears to be highly impacted by human activity including fishing and other recreational activities that cause damage to the reef (e.g. trampling). Successful implementation of coral reef restoration may be dependent upon limiting these activities from occurring through complimentary management activities. Similar to La Passe, no marine economic developments such as aquaculture are known to be planned in Au Cap.

9.3.3 Summary of Benefits

A number of potential benefits can be identified for Au Cap through the implementation of coral reef restoration. A brief description of the likely benefits is provided in Table 9-5. These benefits have been identified at a high level at this stage of the assessment. A more detailed CBA would require further clarity on the extent to which benefits can be attributed to individual project outcomes.

The guidance framework identified several additional benefits to those described in Table 9-5. The 'other benefits' include employment benefits, education/training benefits and other funding provided. These benefits will be important to consider as part of the overall evaluation as the approach to reef restoration is confirmed.

Table 9-5 Overview of expected benefits of coral reef restoration in Au Cap

	Description
Benefits	
Tourism benefits	The key drivers of tourism benefits include: • Increased visitation and use value for tourists of the beach due to reduced erosion, and reduced need for grey infrastructure in the future. Research by Phillips (2011) showed that significant value is placed on beaches without manmade protection infrastructure such as groynes or sea walls. • Potential for increased snorkelling, diving and fishing recreation from tourists due to increases in live coral and other marine biomass, which is currently limited in Au Cap but has been demonstrated to have a high value in other studies. • There are also potential benefits delivered by reduced damage from flooding which would otherwise negatively affect the tourism industry in Au Cap. The total value of these benefits is likely to be much lower than in La Passe due to the lower levels of tourism in Au Cap in addition to the more highly modified shoreline (existing sea walls, for example). There are limited dive and snorkelling activities and the area is not known to have a large tourism industry (compared to other areas of Mahé and other islands in the Seychelles). The CZMU (2018) identifies four hotels within the area affected by 1-in-25-year flood events.
Community benefits	Community benefits are likely to occur in Au Cap as a result of the coral reef restoration activities. The key drivers for community benefits include: • Increased visitation and use value of the beach for local residents as described above. • Increased visitation and recreation value from snorkelling and diving for local residents as described above. • Increased recreational fishing value for local residents • Increased non-use value of the coral reef due to existence, bequest and cultural values. • Reduced flood damage costs to private property in the area, or reduced expenditure on private flood protection. The value of these benefits may be lower than in La Passe due to the modified condition of the beach. However, the local population

	Description
	in Au Cap is 4,274 and the total value of community benefits may be significantly higher.
Local business benefits (non-tourism related)	Local business benefits in this area may include: • Commercial fishing benefits. Artisanal fishing is of paramount importance to the Seychellois. It is largely limited to the Mahé Plateau that comprises the islands of Mahé, Praslin, and La Digue. The plateau is fished by 140 whaler- and schooner-type vessels and at least 400 outboard motor vessels, as well as sport and recreational fishing boats. The total annual landed catch amounts to more than 4,000 tons, valued at around $US12.5 million and supplies most of the domestic market. The volume and value of fish catch may be increased due to reef restoration creating value for local businesses both directly and indirectly involved in artisanal fishing. The artisanal demersal fishery is of paramount importance to the Seychellois. • Depending upon the coral reef restoration type and business model, it may be possible that a local business is expanded to undertake additional coral reef propagation and gardening, or other activities associated with reef restoration.
Other ecosystem service benefits (e.g. value of carbon sequestered)	Other ecosystem services identified around Au Cap include carbon sequestration within sargassum (a type of seaweed). Depending on the extent to which reef restoration protects these ecosystems there will be benefits due to an increase or prevented decline in these services.
Avoided infrastructure costs	There are likely to be improved beach protection outcomes due to coral reef restoration. In Au Cap this reduces the cost of maintaining or replacing beach or flood protection measures such as sea walls or groynes that are already in place, or the construction of additional measures. There are also avoided replacement costs of damaged infrastructure (e.g. roads) due to flooding.

9.3.4 Results of Multi-criteria Analysis

A desktop multi-criteria analysis (MCA) was undertaken to further support the economic evaluation. Three possible options for coral reef restoration were used inform the MCA, which highlights the different types of benefits possible. The three options are:

- Option 1: Artificial reef sited to reduce wave runup – involves developing and deploying new artificial structures to support protection from flooding and erosion.
- Option 2: Artificial reef with coral gardening sited to support coral growth – involves developing and deploying new artificial structures with additional provision of live coral on new substrate.
- Option 3: Coral Gardening, Transplantation and Microfragmentation – involves the provision of live coral on existing substrate.

All three options have been assessed relative to a “no action” scenario, whereby no coral reef restoration activities are undertaken. The results of the desktop MCA are presented in Table 9-6.

Table 9-6 Summary of results from multi-criteria analysis

Benefit type	Weighting	Option 1	Option 2	Option 3
Benefits				
Tourism benefits including benefits for businesses	10%	2	3	2
Community benefits including coastal resilience	30%	3	2	1
Local business benefits (non-tourism related)	20%	1	3	3
Other ecosystem service benefits	10%	3	2	2
Avoided infrastructure costs	30%	4	3	2
FINAL SCORE (weighted total)		**2.7**	**2.5**	**1.8**
Costs				
Upfront expenditure		High	Medium	Medium
Ongoing maintenance		Low	Medium	High
Opportunity costs		Low	Medium	High
Risks				
		Low	Medium	High

The value of the benefits assessed through the MCA are related to both the description of the benefits provided in Table 9-5, and to the specific reef restoration options described above. The weightings given to each benefit are based on the expected scale of the benefits and likelihood of being achieved. These weightings have been tested with the project team in the Seychelles. The relative weightings of the benefits have been adjusted from those used in the assessment of La Passe to reflect the lower importance of tourism benefits in this area. The rationale for the relative benefits between each option are expected to be the same as for La Passe.

9.3.5 Conclusions

The desktop economic analysis of Au Cap highlighted that coral reef restoration will provide several important economic benefits. The benefits which are likely to deliver the highest value in Au Cap are:

- Community benefits: community benefits are likely to be higher than other benefits such as tourism. Community benefits will be provided if the coral reef restoration protects the beaches used by the local community and private dwellings in Au Cap. Additional benefits may occur if the coral reef restoration technique involves an increase in live coral and increases fish and other marine biomass.
- Avoided infrastructure costs: coral reef restoration can also offset future infrastructure requirements to protect the coast from erosion and reduce costs of replacing infrastructure damaged by flooding.

The rapid MCA assessment demonstrates that Options 1 and 2 are the most likely to deliver the highest benefits. This is due to the greater values delivered by flood protection and reduced beach erosion in this area. Option 1 also has the lowest ongoing costs and the lowest risks. Reef restoration using live coral is not likely to be possible at Au Cap, limiting the options available for restoration to Option 1.

The three reef restoration options are potentially suitable for a number of different financing mechanisms. However, it is likely that private financing is not suitable in this area, as the benefits are distributed across the local community under all three options. If coral reef restoration activities were undertaken in this area, it may therefore by more appropriately financed by government.

9.4 Outcomes

9.4.1 Ecological Potential and Risks

Our preliminary framework application to key Seychelles focus areas provides a first pass assessment of coral reef restoration potential, based only on environmental and/or bio-physical criteria (i.e. excludes economic/financial, regulatory, user constraints, logistical etc.).

There are valid objectives for coral restoration at every location in this study. The predominant objective is to reduce beach erosion, although in some locations the tourism and fishery potential that can be realised through enhanced reef structure and biodiversity is also a primary objective. The scale at which restoration is required is generally along the entire reef at each location as a result of the significant loss of coral from bleaching events, combined with the continued pressure at most locations from fishers, people trampling on the reef while hunting octopus, and also from tourists. There is little protection in place to reduce pressures although few locations are in marine parks. The beaches are generally faced with a high energy wave environment for part of the year as a result of the trade winds (SE or NW), which can impacts some beaches. In some bays part of the reef is protected from the influence of trade winds, with a lower energy environment being present year-round. The habitat diversity varies between locations, some having a range of habitats including wetlands, mangroves, saltmarsh and remnant coral, others have bedrock reefs covered by algae, with low coral cover.

Most locations exhibit the potential for restoration, but it is highly unlikely that results will be realised at these locations without active management and protection. Sites on small protected or uninhabited islands are appropriate for restoration, but will not deliver outcomes such as foreshore protection or supporting the tourism industry.

From a purely environmental / bio-physical perspective, the focus areas showing the greatest potential for coral reef restoration were Anse Boileau, Baie Ternay and Beau Vallon (all on Mahe), as well as Petite Soeur and Grand Soeur. Au Cap and La Passe, the selected study sites for this assessment, were identified as having good potential for coral restoration, but that additional approaches and active management would required to achieve restoration objectives.

9.4.2 Economic Case Study Recommendation

To inform the rapid selection of a case study site, we developed key evaluation criteria to be used. These are indicative, recognising that there may be additional preferences of stakeholders or that one of the factors may hold a greater importance over another (the evaluation criteria are not weighted). The evaluation criteria used are summarised in Section 8.2.7. The summary draws off the economic evaluation undertaken as well as other key factors important for this project, including the alignment with policy priorities, specifically Seychelles' Blue Economy Roadmap, an initial analysis for potential private financing options as well as scalability.

A high-level assessment of the two study sites has been undertaken using the evaluation criteria in order to help inform the selection of an appropriate case study site for detailed analysis as part of Task 3. A summary of the high-level evaluation of the known characteristics of the two study sites is provided in summary in Table .

Table 9-7 Evaluation of two study sites for the purpose of selecting a case study site

Evaluation criteria	La Passe	Au Cap
Technical feasibility	• Reef restoration using live corals is limited to the reef slope with other techniques applicable to the reef flat • Management of anthropogenic activities will be required to facilitate restoration	• Reef restoration using live corals is not feasible, a preference for subsurface structures to be used • Management of anthropogenic activities will be required to facilitate restoration to a greater extent than La Passe
Outcomes	• Outcomes more comprehensive and may include increased coral species, ecosystem functions, environmental protection and erosion and flood risk reduction.	• Outcomes likely more limited and unlikely to include increased coral species.
Benefits	• Higher expected total benefit than Au Cap • Benefits expected to include both private (e.g. tourism) and public benefits	• Benefits mostly public, including avoided infrastructure costs and community benefits
Policy alignment	• Strong alignment to Seychelles' Blue Economy Roadmap	• Moderate alignment to Seychelles' Blue Economy Roadmap
Data availability	• Unknown, however initial data provided has included a greater number of prior studies than Au Cap	• Unknown
Financing options	• Greater number of examples and options for private financing given greater proportion of private benefits • Likely to have clear revenue stream from tourism-related benefit	• Fewer number of examples of private financing given greater proportion of public benefits • Less likely to have a clear revenue stream outside of government (avoided costs). However, revenue stream is likely to have a lower risk if the revenue is provided by government.
Scalability	• Likely to be highly scalable given large number of tourism-	• Likely to be highly scalable given potential for coastal resilience benefits around

Evaluation criteria	La Passe	Au Cap
	dependent areas protected by and benefiting from coral reefs • Governance arrangements may be more complex as third-parties need to be actively involved in coral reef restoration options	Mahé, however limited options for private financing. • Governance arrangements likely to be easier given government is central to implementation
Conclusion	• **Preferred case study site**	

10 Business Case Methodology

This section provides a brief overview of the approach and research undertaken to inform the development of the business case. It builds on the economic evaluation methodology presented and the ecological prioritisation and the outputs of Task 1. Key tasks that were undertaken to develop the business case included:

- Development of a framework for the business case;
- A review of previous business models used for conservation financing; and
- An assessment of potential financing mechanisms and revenue streams for coral reef restoration.

The methodology included both desktop research and stakeholder engagement. The findings from the desktop review and stakeholder engagement was further tested and refined with the project team, which includes Marine Conservation Society Seychelles, WiseOceans and University of Seychelles, and through World Bank consultations.

10.1 Business Case Framework

The initial task was to develop an appropriate framework for the business case. The design of the business case has been informed by the key elements of the Strategyzer Business Model Canvas template (see Appendix A). The Strategyzer Business Model Canvas has been used to develop other coral reef restoration strategies, such as those presented by Vertigo Lab (2017). This approach was further refined and tested with other business case frameworks and requirements from the Request for Quote for this project, which resulted in the inclusion of strategic risks as well as a high-level performance and monitoring plan. The final business case framework is designed to inform a tangible path forward, or ‘roadmap’, for the implementation of large-scale coral reef restoration in Seychelles. The framework has been used to provide the structure to Section 3 of this report.

10.2 Stakeholder Engagement

An important element of this report methodology has been stakeholder engagement. Although Task 2 focussed on the economic evaluation phase of the overall project, the paucity of available data required us to seek further data and information through stakeholder consultations with relevant experts in Seychelles. Stakeholder engagement was therefore undertaken for two purposes:

- Data and information gathering to inform the economic analysis, in particular to request specific data (based on a detailed Request for Information) and potential data sources for the economic study.
- Further development of the business case, to gather thoughts on potential ideas, opportunities and risks of developing a business case for large-scale coral reef restoration in Seychelles.

A list of stakeholders is provided in Table 3-2. The stakeholder engagement further highlighted the paucity of data that was available to inform the development of a business case. In particular, there was limited data available to undertake a specific economic evaluation for La Passe. Consequently, the primary business case findings have been on large-scale coral reef restoration in Seychelles, with the use of Seychelles-wide data. A key finding of this work is the imperative for future research to provide robust evidence on the net benefits of coral reef restoration at scale in the Seychelles.

10.3 Business Models for Conservation Financing

This section presents the findings and lessons from a high-level review of business models that have been used to finance conservation outcomes, particularly those used for coral reef restoration as well as those already being delivered in Seychelles. A growing base of literature on financing coral reefs is being established. Of particular note is the comprehensive summary and review of approaches by the International Coral Reef Initiative (Vertigo Lab 2017) and Wildlife Conservation Society in partnership with 50 Reefs and the Conservation Finance Alliance (Lyer et al 2018). In the Seychelles specifically, a recent study by Goizueta (2018) examined the potential to invest in coral reefs on La Digue through engagement with the tourism sector. The review undertaken for this project identified and reviewed (as opposed to replicated) the existing literature available on this topic. The review was used to identify critical factors to guide the development of the business case presented in this report and identified:

- Key principles of business models, to inform the design of the business model used in the business case; and
- Key lessons learnt from the implementation of business models, to inform the development of appropriate implementation arrangements.

Further information on the business model review is provided in Appendix B.

Innovative approaches to financing of coral reef restoration have become an important area of conservation finance. Coral reefs, along with other natural coastal ecosystems, are recognised for their significant coastal resilience benefits and other co-benefits, such as tourism. Financing for their restoration and management has largely been the responsibility of public funds, however current funding is not sufficient in consideration of the magnitude of the risks faced by coastal ecosystems. Private financing is needed to close the gap between public expenditure and the funding requirements. In recognition of the range of benefits coral reefs provide, new and innovative approaches to financing coral reefs have been developed.

The business model review has identified key lessons for successful implementation of a conservation strategy, which include:

- Identify and understand the widest range of benefits that the conservation strategy will provide. This enables consideration of potential beneficiaries of the strategy and, consequently, what revenue streams may be reasonable and attributable to the strategy.
- Communicate the benefits of the conservation strategy by engaging with the key stakeholders early in the process. Engagement with beneficiaries and other important stakeholders (e.g. future administrators or implementors) or partners is critical. Government, along with support from development banks and international non-governmental organisations (NGOs), has an important role to play in engaging key stakeholders, particularly through the strategy development process.
- Establish a clear evidence base for the strategy. The evidence base will be used to inform the final business case and for communication and engagement. This may require additional studies

to inform the strategy, as well as effective monitoring, evaluation and reporting throughout its delivery.

- Governance arrangements should be as simple and practical as possible, and ensure a high-degree of transparency. Once critical stakeholders have engaged with the strategy, it is important to maintain their trust. Effective governance will ensure this without risking perceptions of, for example, mismanagement of funds. Appropriate monitoring, evaluation and reporting of the progress being made by the conservation strategy is an important element of effective governance. The use of the conservation trust fund has been a successful governance mechanism to support the delivery of conservation financing strategies.
- Government has a key role to play in the development and delivery of a conservation strategy. Their role includes both direct involvement with the project, likely including funding of some type, as well providing the appropriate policy and regulatory environment for the strategy to be a success.
- Use existing structures and processes where feasible and practical. The development of a strategy to implement coral reef restoration can take time. Given the complexity of such a strategy, it can be beneficial to use existing structures to help streamline the development process.

These findings have been used to inform the development of the business case provided in Section 11.

10.3.1 Financing Mechanisms and Revenue Streams

This section presents an overview of the findings from an assessment of the financing mechanisms that may be most appropriate for large-scale reef restoration in the Seychelles. The assessment included assessment of both potential sources of capital and potential revenue streams. The assessment did not attempt to provide a complete overview or comparison of all financing structures and arrangements.

A set of criteria were developed to identify appropriate sources of capital for the program. The criteria were used to inform the identification of potential sources of capital to finance the business case presented in Section 12. The criteria and their implications for coral reef restoration are provided in Appendix D. The criteria have been adapted from a prior study examining the mechanism to finance climate change adaptation (Banhalmi-Zakar et.al. 2016) and the principles of financing (including project financing). The assessment focused on identifying how non-government sources of capital could be used wherever possible to supplement public financing.

The types of capital assessed include grants and debt. The use of equity to fund coral reef restoration has not been considered extensively as this would require the establishment of a corporatized entity for the program, which was not one of the recommended options for implementation. However, equity financing could be possible if, for example, a large, centralised, coral nursery is established that functions as a standalone business venture.

The different sources of capital considered for this business case and the expected financial returns are:

- Government grants as well as guarantees (no financial return);

- Commercial debt market (market rate);
- Impact investor or concessionary debt (lower than market rate return, e.g. 3 percent);
- Development bank grants or concessionary debt as well as guarantees (mixed, depending upon capital source, i.e. no financial return – three percent); and
- Philanthropic grants (no financial return).

However, financing assessment criteria form just one part of the decision-making process on financing. Other non-financing related criteria may also need to be considered. The most important non-financing criteria for the purposes of this project is understanding the capacity of Seychelles Government to fund the coral reef restoration. The Seychelles Government does not necessarily have the capacity to fund the project at this time. Furthermore, innovative ways to attract alternative sources of capital to construct public-private partnerships are being deployed globally. Consequently, public-private or private financing mechanisms are sought for these types of projects, which deliver either environmental or social benefits and can provide a return on investment.

The financing assessment demonstrated that there is a clear rationale for non-government sources of capital to fund large-scale coral reef restoration. This would include grants from philanthropic or development banks as well as concessionary debt from impact investors. Development banks and government also play an important role in de-risking debt investments through, for example, guarantees and the provision of funding for the development of the program. While grants should be prioritised, as they reduce the amount of debt required, it is likely that only a portion of the coral reef restoration effort would be funded by grants. Consequently, debt would be a required source of capital for the program. A clear revenue stream for the program would also be required to repay the debt as well as fund ongoing program management costs.

Revenue streams that provide potential options for financing coral reef restoration have been identified in Appendix D, with the most appropriate being analysed to inform the business case. The assessment identified several potential revenue streams that could be used to finance large-scale coral reef restoration in Seychelles. The selection of the most appropriate revenue stream will be informed by the scale of implementation, the beneficiaries and the willingness to introduce new taxes, fees or levies. A clear rationale, value proposition and implementation strategy for any such arrangement would need to be identified and communicated to those affected.

11 A Business Case for Large-scale Coral-reef Restoration

This section presents the business case for a program of coral reef restoration for the Seychelles with a specific illustrative case study at La Passe. The business case is designed to provide a high-level but tangible path forward for the implementation of the program.

The business case has been informed by consolidating outputs from prior tasks of the project and testing findings through consultation with stakeholders (as discussed in our methodology presented in Section 10). This section presents the key findings, implications and recommendations from this process.

11.1 Introduction to Case Study Site at La Passe (La Digue)

Two options were considered for a case study site - La Passe and Au Cap (Mahé). La Passe has been selected as an illustrative case study site for this project. La Passe was selected as it provides a clearer demonstration of a range of factors presented in the business case. For example, undertaking coral reef restoration at La Passe is expected to include both coastal protection and tourism benefits, whilst Au Cap is less likely to demonstrate tourism benefits. The selection of La Passe as a case study site does not indicate that it is the highest priority site for coral reef restoration in Seychelles. The ecological surveys undertaken during Task 1 focussed on La Passe, however for the economic case study we have considered the La Passe area more broadly. More detail on the case study site is provided in Appendix E.

La Digue is an important tourism destination, with between a quarter and a third of all tourists visiting Seychelles visiting La Digue, resulting in tourists outnumbering local residents five to one in peak season. This has implications for water use, sanitation and the impact on natural environment (including coral reefs), requiring appropriate management to be put in place. The La Passe site comprises the primary area of economic activity on the island. The area includes a range of environmental, social and economic assets, including:

- Hotels, private residences, cafes and restaurants;
- Hospitals, marina and roads;
- Extensive sandy beaches and lagoons;
- Large areas of seagrass and areas of coastal mangroves to the south of La Passe; and
- Limited agricultural land.

The coral reef on the western coastline provides protection for these assets as well as being an attraction for tourists and locals. The reef condition is considered to be poor, with very low live coral cover compared to other species and large areas of rubble and bare rock (BMT 2019).

11.2 Business Case for Large-scale Coral Reef Restoration

The structure of the business case, which was developed through the methodology described in Section 10, includes:

- Overview of the problem – the key issues that this program seeks to address.

- Overview of the proposed solution – the method by which this program proposes to address the key issues.
- Benefits of coral reef restoration in Seychelles – the benefits and beneficiaries of the activities delivered by the program.
- Key activities, partners and resources – the activities required to implement the program and the supporting activities and resources on which the program will depend.
- Governance arrangements – the proposed governance arrangements for the program, including the roles and responsibilities of the key delivery organisations.
- Costs structures – the costs to deliver the key activities of the program.
- Financing and revenue streams – the potential revenue streams and sources of capital that could be used to finance the program.
- Strategic risks – the strategic risks that could affect the success of the program.
- High level performance and monitoring plan – the critical ecological and other outcomes, indicators and data sources to measure the performance of the program.

This structure facilitates the presentation of a business case that can be used to provide guidance on the most appropriate pathway to implementation of large-scale coral reef restoration in the Seychelles. The approach outlined in the business case should be further tested and refined by stakeholders in the Seychelles, and further data may be needed before the final approach is implemented. It should also be noted that the policy landscape is changing rapidly, with several ongoing interdependent projects underway or soon to commence. One such example is the development of a coral reef policy for Seychelles. Stakeholder engagement is important to ensure alignment with this policy and other programs.

11.2.1 Overview of the Problem

Coral reefs provide vital ecosystem services in the Seychelles. The presence of coral reefs provides coastal protection through mitigation of wave energy, protecting from coastal flooding and reducing beach erosion. The increased biodiversity associated with coral reefs provides recreational benefits to divers and snorkellers, which generates tourism in local areas and can also provide benefits to local fisheries. Coral reefs also have high non-use value, with both locals and tourist valuing the reefs' existence, whether or not they visit them. These important ecosystem services are under threat, both in the Seychelles and around the globe, due mainly to climate change and human activity.

Coral reefs in the Seychelles are at risk, and much of the coral is already in poor condition. The primary threat is from climate change, which causes coral bleaching events. An event in 2016 led to 50 percent coral mortality rate across surveyed reefs in the Seychelles (Gudka et al, 2018). Human activities on or near to reefs can cause damage from trampling, anchor damage from boats, and pollutant such as sunscreen. Run-off from farming and flooding can increase nutrients in the waters around the reef, causing algal blooms and leading to suffocation of corals. These effects have led to the current poor condition of the reefs around the Seychelles, putting the ecosystem services they provide at risk.

This project focussed predominantly on understanding how coral reefs could be used to help alleviate the damage caused by coastal erosion and flood. The costs of coastal flooding, exacerbated by damage to reef systems, are potentially significant in the Seychelles. For example, in 2013 heavy rains from tropical cyclone Felleng caused severe flooding. The estimated damage costs were $US8.4 million (Government of Seychelles, 2013). Whilst this damage was not a result of coastal flooding, most development in the Seychelles is located on the coastal plateau and so would be similarly affected due to coastal flooding. Currently, the government manages flood risk and coastal erosion responsively rather than proactively, however this is unsustainable for the Seychelles Government, and these costs may continue to grow due to climate change and increased development. Alternative adaptive management options to increase coastal protection (including coral reef restoration) are therefore currently being explored by the Seychelles Government.

La Passe – Overview of the problem

La Passe is similar to many other areas of Seychelles. The reef condition is poor, with very low live coral cover compared to other species and large areas of coral rubble and bare rock. A recent assessment at La Passe showed little evidence of any recently dead coral at the site, suggesting that the lack of coral is likely to be due to historic bleaching events. High risks of flooding and beach erosion have been identified in the La Passe area. To date, restoration work has included the construction of a groyne and a seawall next to the harbour. Tourists visit La Digue because of the beaches and culture of the island (Goizueta, 2018). Erosion of the beaches, or use of hard infrastructure to manage erosion, are likely to reduce the appeal of the island to tourists.

11.2.2 Overview of Proposed Solution

A potential option to reduce the risks to the ecosystem services in the Seychelles is coral reef restoration. As part of this project potential sites for coral reef restoration throughout Seychelles were identified and assessed for their suitability for coral reef restoration. Coral reef restoration was assessed as a feasible undertaking at a number of sites in Seychelles and consequently this project has identified significant scope for undertaking large-scale coral reef restoration in the Seychelles.

For most of the sites identified the primary objective of coral reef restoration is to alleviate the damage caused by coastal erosion and flood events. In some locations the tourism and fishery potential that can be realised through enhanced reef structure and biodiversity is also a key objective. The scale of restoration required at each location typically encompasses the entire reef. This is a result of the significant loss of coral from bleaching events, combined with the continued pressure at most locations from fishers, people trampling on the reef while hunting octopus, and also from tourists. The habitat diversity varies between locations, some having a range of habitats including wetlands, mangroves, saltmarsh and remnant coral, others have bedrock reefs covered by algae, with low coral cover. For each priority site a range of benefits of coral reef restoration have been identified, however coastal protection is the key benefit at the majority of sites.

Given the critical problem this project has sought to address, the predominant focus of this business case is therefore on the use of coral reef restoration to alleviate the damage caused by coastal erosion and flood events. Consequently, the assessment of different restoration options has been prioritised to maximise this outcome in a reasonable timeframe.

11.2.3 Overview of Restoration Options

Phase 1 of this report provided an initial prioritisation of restoration sites based on a range of criteria, primarily ecological and the most likely restoration type at each site. The differences in restoration options have been investigated in terms of project feasibility from an economic perspective. Three options were considered (artificial reef only, live corals only, hybrid approach) to provide an indicative basis for understanding the type and timing of benefits to resolve the problem that this business case seeks to resolve. These options are described in detail in Section 5. An overview of the costs per m^2 for each option is provided in Appendix G.

The preferred option for the majority of sites was a hybrid approach, which uses both artificial reefs and live corals. This approach provides greater certainty that the primary outcomes sought from this program will be achieved, while also providing a range of important co-benefits (see Section 11.2.4).

It is important to note that each site would have its own mix of restoration options, which would require detailed project feasibility analysis prior to the funding of implementation of coral reef restoration. For example, some sites identified as being priority sites from an ecological perspective would only include the use of live corals.

The business case has used the prioritisation and feasibility assessment undertaken through in the economic evaluation, as well as a focus on the critical problem (coastal resilience) as the basis for the assessment and development of this business case.

11.2.4 Benefits of Coral Reef Restoration in Seychelles

Table 11-1 sets out the key benefits of undertaking coral reef restoration in Seychelles using the preferred coral reef restoration option (hybrid approach).

The benefits identified in Table 11-1 provide guidance on the beneficiaries of the program, and consequently who the ‘customers’ are for this program. The identification of customers in this way provides an indication of who may be willing to pay for the coral reef restoration and therefore what potential revenue streams may exist to finance the program. The potential customers for this program are varied and include:

- Government which benefits from avoided costs to deploy infrastructure solutions, avoided costs of flood damage and increased tax revenues from tourism activities.
- Local residents who see existence benefits for biodiverse coral reefs, access to beaches, lower impacts from flooding and coastal erosion.
- Tourism businesses seeking to either increase tourism visitation, add higher value tourism offerings, or prevent declining tourism due to perceived declines in the ecological value of the Seychelles.
- Tourists who benefit from access to high quality beaches, and healthy, biodiverse coral reefs.
- Other local businesses which may benefit from avoided flood damage costs, increased fisheries value or new business opportunities related to reef restoration.
- Corporations or other bodies (including through secondary markets) interested in purchasing carbon credits or biodiversity outcomes.

The potential revenue streams are identified and quantified in Section 11.2.8 of this business case.

Table 11-1 Summary of benefits identified for coral reef restoration in Seychelles

Benefits	Description
Avoided infrastructure costs	There are likely to be improved beach protection outcomes due to coral reef restoration. This would reduce the cost of implementing new beach or flood protection measures such as sea walls or groynes, or replacement of damaged infrastructure (e.g. roads and hospitals) due to flooding. The CZMU (2018) shows that approximately 10 kilometres of roads as well as the hospital and community centre are within the area affected by 1-in-25-year flood events. A Coastal Management Plan currently being proposed to the Seychelles Government has identified $13 million of investment in coastal protection measures which should be prioritised before 2025.
Tourism benefits	Tourism benefits are likely to accrue as a result of coral reef restoration. The key drivers of tourism benefits include: • Increased visitation and beach use value for tourists due to reduced erosion, and reduced need for protective infrastructure in the future. Research by Phillips (2011) showed that significant value is placed on beaches without manmade protection infrastructure such as groynes or sea walls. • Potential for increased snorkelling, diving and fishing recreation from tourists due to increases in live coral and other marine biomass. Diving and snorkelling may also see increases due to the actual activity of coral reef restoration as has been demonstrated in other areas in the Seychelles (e.g. Curieuse). • There are also potential benefits from reduced flood damage which would otherwise negatively affect the tourism industry. For example, the CZMU (2018) identified hotels and roads that would be affected by 1 in 25-year floods, which would affect tourism in the area. The Seychelles is visited by a significant number of tourists each year, therefore these benefits are likely to be highly important to the overall value of the coral reef restoration projects. Furthermore, it is likely that continued environmental degradation will reduce the appeal of the Seychelles to tourists in future. Failure to protect beaches and coral reefs will lead to a decline in tourist visitation, negatively effecting the Seychelles economy. Research in St Vincent and the Grenadines (Christie et al, 2015) demonstrated that tourists were willing to pay $88.48 per household per year to improve six ecosystem services including; fishing, coastal protection, human health, ecosystem resilience, beach recreation, and diving/snorkelling.
Community benefits	Community benefits are also likely to occur as a result of the coral reef restoration activities. The key drivers for community benefits include: • Increased visitation and use value of the beach for local residents as described above. • Increased visitation and recreation value from snorkelling, diving and fishing for local residents as described above. • Reduced flood damage costs to private property in the area, or reduced expenditure on private flood protection. • Increased non-use value of the coral reef due to existence, bequest and cultural values. These benefits on a per person basis may be relatively high, for example the study in St Vincent and the Grenadines discussed above found that locals had a willingness-to-pay of $54.41 for improvement in six ecosystem service benefits.

Benefits	Description
Local business benefits (non-tourism related)	Artisanal fishing is of paramount importance to the Seychellois. This activity is largely limited to the Mahé Plateau that comprises the islands of Mahé, Praslin, and La Digue. The plateau is fished by 140 whaler- and schooner-type vessels and at least 400 outboard motor vessels, as well as sport and recreational fishing boats. The total annual landed catch amounts to more than 4,000 tons, valued at around $US12.5 million (World Bank, 2017). The volume and value of fish catch may increase as a result of reef restoration. This will create value for local businesses both directly and indirectly involved in artisanal fishing. In addition to fishing, local businesses may be established to undertake coral reef propagation and gardening or other activities associated with reef restoration. Viability of such ventures will depend upon the coral reef restoration type and business model implemented. Currently, these types of business activities occur on Mahé.
Other ecosystem service benefits (e.g. value of carbon sequestered)	Other ecosystem services identified include carbon sequestration within seagrass beds and mangroves. Depending on the extent to which reef restoration protects these ecosystems there will be benefits due to an increase or prevented decline in these services. The estimated rate of carbon sequestration for seagrasses and mangroves is 607 tCO_2e/ha[1] and 1494tCO_2e/ha respectively. Assuming a carbon price of $10/$tCO_2e$ would suggest a carbon value of $6,070/ha for seagrasses and $14,940/ha for mangroves.

1 https://www.thebluecarboninitiative.org/about-blue-carbon

La Passe – Cost and benefits of coral reef restoration

Three possible options for coral reef restoration were assessed for La Passe. The three options are set out here, with identified costs, benefits and risks.

(1) Artificial reef sited to reduce wave runup – involves developing and deploying new artificial structures to provide protection from flooding and erosion. For this option:

(a) Upfront costs to implement restoration are $84,000, no ongoing management costs identified.

(b) Benefits are only associated with coastal protection through reduced wave runup. This includes avoided infrastructure costs, tourism benefits and community benefits. No benefits associated with additional biodiversity have been identified, given the low likelihood of natural coral propagation in this area.

(c) The risk of outcomes not being achieved is low, as this option does not include any live coral there is no risk associated with climate change or human activities negatively affecting the outcomes identified.

(2) Artificial reef with coral gardening sited to support coral growth – involves developing and deploying new artificial structures with additional provision of live coral on new substrate. For this option:

(a) Upfront costs to implement restoration are $722,800 with $48,000 per annum ongoing costs.

(b) Benefits are associated with coastal protection including reduced flood risk and reduced beach erosion, as well increased biodiversity supporting fishing, tourism and recreation. This includes avoided infrastructure costs, tourism benefits, community and local business benefits and ecosystem service benefits.

(c) The risk of outcomes not being achieved is medium. This option includes live coral, which will face risks associated with climate change and human activities, however the presence of the artificial reef structure allows for some benefits even where full coral death occurs.

(3) Coral Gardening, Transplantation - involves the provision of live coral on existing substrate. For this option:

Upfront costs to implement restoration are $363,200 with $48,000 per annum ongoing costs.

(a) Benefits are associated mainly with biodiversity and recreational outcomes. Significant coastal protection benefits are unlikely to result from this option. These benefits therefore include ecosystem service benefits and tourism benefits but no avoided infrastructure costs.

(b) The risk of outcomes not being achieved is high. All benefits are associated with the presence of live coral, which are at risk from climate change and human activities.

As a result of this assessment the key focus for the business case is on implementing coral reef restoration using a hybrid approach with both artificial reef structures and live coral, which would ensure that the key outcomes of coastal protection and biodiversity are achieved. This approach, although at higher cost, will deliver a wider range of benefits, and be more suitable to a public-private financing approach because of the greater potential for a range of funding mechanisms, sources of capital and revenue streams. These will be discussed further throughout the business case.

11.2.5 Key Activities, Partners and Resources

11.2.5.1 Key Activities

A number of key activities are required to effectively implement large-scale coral reef restoration in Seychelles. Table 11-2 provides a summary of these activities, the risks or constraints that need to be managed and the organisations proposed to implement each activity. The proposed implementing organisations have been suggested on the basis of their ability to overcome the risks or constraints that have been identified to manage.

A more detailed description of the role and responsibilities of each proposed implementing organisation is described in detail in Table 11-3. The financing arrangements are discussed in Section 11.2.8.

Table 11-2 Overview of key activities to implement the project

Key activity	Risks or constraints to manage	Proposed implementing organisation(s)
Establish and manage coral reef nursery	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and, commercial business
Site-specific project design, including use of artificial reef	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and, commercial business
Implementation of coral reef restoration, e.g. coral gardening and transplantation	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and, commercial business
Monitoring of rehabilitated coral reef	Sufficient capacity and capability to deliver a project of this scale, which has not been undertaken in Seychelles previously	Consortium of NGOs, Universities and, commercial business
Governance and administration	Ineffective governance and a lack of administrative capacity and capability can prevent the program from being	Independent administrative organisation

Key activity	Risks or constraints to manage	Proposed implementing organisation(s)
	implemented, including attraction of finance, due to the higher risk of program-failure	
Marketing, communication and stakeholder engagement	Ineffective communication may result in disengagement or loss of confidence in the project. This may lead to a loss of support for the program and a loss of parties with sufficient capacity to implement	Independent administrative organisation
Monitoring, evaluation and reporting (MER)	Ineffective MER may prevent objectives from being achieving due to a lack of adaptive management of risks	Independent administrative organisation

Box 1 – Coral Reef Nurseries

The delivery of the program requires a significant number of coral fragments. This business case has assumed that the implementation of the coral reef restoration would occur within six years. To accommodate this timeline, and given that restoration needs to occur across locations throughout the Seychelles, multiple large-scale nurseries are required. If investment in large-scale nurseries cannot be undertaken, a large number of small-scale nurseries (which may not be feasible) or a scaling back of restoration across the Seychelles would be required.

The coral nurseries can be land or ocean based, both with inherent benefits and risks.

Land-based nurseries have the following key benefits and risks:

- Greater control over exogenous events (such as bleaching events) than ocean-based nurseries
- Potential to increase efficiencies due to greater control, greater certainty of supply
- Requires access to significant land with access to clean sea water
- Requires significant energy and other costs
- Higher cost per coral fragment.

Ocean-based nurseries have the following key benefits and risks

- Ability to scale production up and down with less financial impact (i.e. land-based nursery requires larger upfront capital and operating expense)
- Lower cost per coral fragment
- Single event (such as bleaching) could destroy entire nursery and disrupt supply
- May be classified as an aquaculture activity requiring specific Environmental Impact Assessment and associated compliance costs.[2]

A combination of nursey types and locations is proposed to help to manage these costs and risks and diversify the coral fragment supply chain. Consequently, in calculating the costs for the program the following nurseries are assumed to be developed:

- One land-based coral reef nursery, Mahe, 15,000 fragment capacity
- One land-based coral reef nursery, La Digue, 5,000 fragment capacity
- Two ocean-based nurseries where identified as suitable in the prioritised sites (Appendix F), with one at Baie Ternay and one at either Grand or Petite Soeur, 5,000 fragment capacity.

This is a significant step-change in the scale of current land-based nurseries in the Seychelles (usually around 200-1000 fragments) and would require a central tank facility, possibly linked with a major institution such as the University of Seychelles. However, Nature Seychelles (for example) has already established a substantive ocean-based nursery that has produced approximately 50,000 fragments over 8 years. It will be important to draw from these experiences in the final nursery arrangements.

La Passe – Key Activities

The key activities for La Passe align with those presented for the Seychelles project. However, the scale of implementation is significantly smaller and the focus of the activities is more targeted. For example, a single, 1000 fragment per cycle, land-based nursery could be used to implement the project on La Passe only.

11.2.5.2 Supporting Activities and Key Partners

In addition to the activities related specifically to the implementation of the program, a range of supporting activities provided through delivery partners are critical to its success. Each key partner will need to have the necessary capacity and capability to help deliver the overall program. Table 11-3 provides an overview of the key partners, supporting activities, risks or constraints and the recommended action. The recommended action is proposed to be delivered by the lead Seychelles Government agency and/or program partners (e.g. the World Bank), consistent with the proposed role of Seychelles Government. The recommended action is proposed on the basis that it would help to overcome or manage the identified risk or constraint. For example, the overall capacity of Seychelles government agencies and ministries is limited and consequently its efforts to support the program would need to be prioritised given significant competing demands. Table 11-3 does not include the role of financing parties, which are detailed in Section 11.2.8.

Of the key partners identified, Seychelles Government will have a critical and fundamental role. The role that government takes will change over time. For example, in the post-feasibility stage (after the conclusion of this project) it will be important that Seychelles Government takes a leading advocacy role to progress the program. Seychelles Government will also need to play a key role in the development phase of the program including the coordination of delivery partners and support for appropriate studies to be undertaken. Once the coral reef restoration is implemented, government agencies will have an important ongoing site management role. Seychelles Government may be supported to undertake some of these roles by, for example, development banks and by NGOs.

The advocacy role of government is particularly important in consideration of the experiences from previous coral reef restoration projects in Seychelles. For example, a coral reef restoration project proposed in the North East of Mahe, which also proposed artificial reef structures, demonstrated that the residents may be opposed to the deployment of artificial structures onto natural remanent coral reefs. Secondly, it will be important to engage with businesses that may be affected by the restoration activities (e.g. restricted access to coral reef restoration sites) and financing mechanism if the CSR or new green levies approach is used (e.g. businesses have previously been opposed to such changes). Consequently, a high degree of stakeholder consultation would be required to successfully implement the program across Seychelles.

It is important to note that there are other policies and programs being developed at this time that may affect the viability of coral reef restoration in certain areas. For example, Seychelles is progressing the development of a coral reef policy that it will be important to align with. The status of these policies and programs is variable however it is expected that they will be developed and finalised over the next few years, which is important in the context of the implementation timeline for this program. Four of the identified priority sites are within Marine Protected Areas including:

- Baie Ternay (Mahé) which is within the Baie Ternay Marine National Park
- Anse Aux Pins and Au Cap (Mahé), which are within the Mahé (Anse Faure-Fairy Land) Shell Reserve
- Anse Boudin (Praslin) which is within the Curieuse Marine National Park.

The Seychelles National Park Authority (SNPA) is currently in the process of development of comprehensive Management Plans for each SNPA site, which are expected to be completed in 2019. There are also fisheries management plans being put into place on both the Mahe plateau and around Praslin in 2019 that will affect the way in which any coral reef restoration can be managed in these areas. Other activities currently being assessed for funding through SeyCATT, such as temporary fisheries closures or the continued development of the aquaculture sector, will also need to be taken into consideration when implementing any coral reef restoration activities. It will be important that these other management activities are understood and considered in the development of specific sites.

Table 11-3 Overview of key partners and supporting activities for the implementation of the program

Key partners	Supporting activity	Risks or constraints	Recommended action by lead government agency/program partners
Seychelles government agencies and ministries	Take a leading role in project development, until establishment Design and implement supportive regulatory and policy (protection, compliance, fiscal) Mobilise resources to implement restoration-dependent management activities (e.g. restricting access to restoration sites) Program advocacy Provide provision of data, information and expertise	Limited capacity given high demand on government agencies to provide these partnering roles across a range of projects	Engage with appropriate agencies and ministries to ensure ownership of program outcomes
Seychelles Hotel and Tourism Association or Seychelles Sustainable Tourism Foundation	Coordinate communication with hotel and tourism businesses	Previously have shown resistance to projects/policies that seek to redirect existing CSR contribution or introduce new levies and fees on tourists	Engage and demonstrate benefits of joint-approach, particularly where fiscal policy (e.g. CSR tax) is used to fund the program

Key partners	Supporting activity	Risks or constraints	Recommended action by lead government agency/program partners
NGOs – individual or consortium	Provide management of coral reef rehabilitation sites including restricting access and controlling activities[3] (currently limited in scope) Assist in marketing and community engagement efforts	Management role may overlap with other roles required to implement the program, including implementation and evaluation which could lead to perceived conflict of interest Priorities driven by NGO priority areas and availability of funding	Engage as part of broader investigation of potential roles to deliver the program and their capacity and capability
Marine Spatial Planning (MSP) project (*new governing body TBC*)	Designate appropriate near-shore coastal environments with prioritised coral reef restoration sites as Marine Protected Areas (MPAs) Allocate funding to support management of MPAs Sharing of data and information to support program feasibility	Timing of decisions and whether they can align with timelines of this project Competing priorities and objectives of near-shore MPAs	Engage with MSP project team to ensure alignment of project outcomes are identified and realised by demonstrating benefits of this approach
Other related projects – Seychelles-Mauritius regional coral reef program, Blue Carbon proposed project, BioFin	Provides policy, funding, research that supports the program	Coordination may be lacking currently which limits the identification and realisation of opportunities for coordination	Engage with relevant project teams to ensure alignment of project outputs and outcomes are identified and realised

3 This will require designation of the sites and the NGO as the management organisation

La Passe – Key partners and supporting activities

The key partners and supporting activities highlighted for the Seychelles program are consistent with those that may be experienced with the case study at La Passe. Of particular note, stakeholder support would be critical to the success of the project when the primary form of revenue is the CSR contribution from businesses on La Passe or where a visitor fee is introduced. Without regulation (which would be unlikely), both of these potential revenue streams would need to be supported by local residents and businesses. Consequently, Seychelles Government and the Seychelles Hotel and Tourism Association or Seychelles Sustainable Tourism Association would need to be strong advocates of the project to elicit and maintain support from local residents and tourist operators.

11.2.5.3 Key Resources

Resourcing for implementation of the program is reliant upon access to a sufficient number of people with appropriate skills and expertise. The use of the key delivery organisations for the program's activities, outlined in the prior sections, is designed to overcome or alleviate resourcing constraints (i.e. by leveraging in-kind support and existing expertise). However, the size of the program will mean that some resourcing constraints will arise and will require a detailed understanding to ensure that this challenge can be overcome. It will be important to engage with existing providers and understand how a collaborative effort may function in practice. Resourcing constraints may include:

- Divers and equipment to undertake transplantation, maintain and monitor each coral reef site;
- Staff to operate the coral reef nurseries;
- Boats and boat operators to undertake transport and transplantation, and ongoing maintenance and monitoring visits;
- Experts to develop feasibility studies including environmental impact assessments, project designs and due diligence studies; and
- Communication and stakeholder engagement specialists.

In addition to having access to the necessary skills and expertise, program delivery will require raw materials, specifically artificial reef structures and live corals. The size of the program will require careful management of supply chains to ensure that the availability of the critical raw materials is not limited or, the supply is sufficiently coordinated to provide price benefits from economies of scale. For example, the use of multiple large, land- and ocean-based nurseries is proposed to secure sufficient supply of live corals to implement the project within six years.

La Passe – Key Resources

It is expected that La Passe will face the same constraints as those identified across the Seychelles. The difference in the size of the La Passe case study means that resource constraints would be more limited. Nonetheless, the La Passe case study includes the delivery of coral reef restoration efforts at a scale above those previously deployed at La Passe.

Resourcing constraints will need to be assessed prior to approving a project on La Passe. For example, it is assumed that a boat with four divers can plant, clean or monitor a 200 m^2 area in a day (undertaking two dives each). For the 1000 m^2 area identified for the La Passe site that suggests that you would require four days for planting the coral, however you would then also need 4 days a month for two divers to undertake monitoring activities. This could be a significant restraint to undertaking these monitoring activities if it is difficult to consistently employ two divers for four days each month, as well as hire a boat and equipment.

11.2.6 Governance Arrangements

The delivery of the program is proposed to mirror a similar structure to the coral reef restoration business models reviewed as part of the methodology. These models have been used successfully in other countries. The proposed arrangements for the implementation of the program are summarised in Figure 11-1. Specific roles and responsibilities are described using the following high-level roles and responsibility requirements identified as necessary from the business model review (Section 10 and Appendix B), which are:

- Administrator;
- Implementor;
- Evaluator; and
- Financing – note that this is provided in Section 11.2.8.

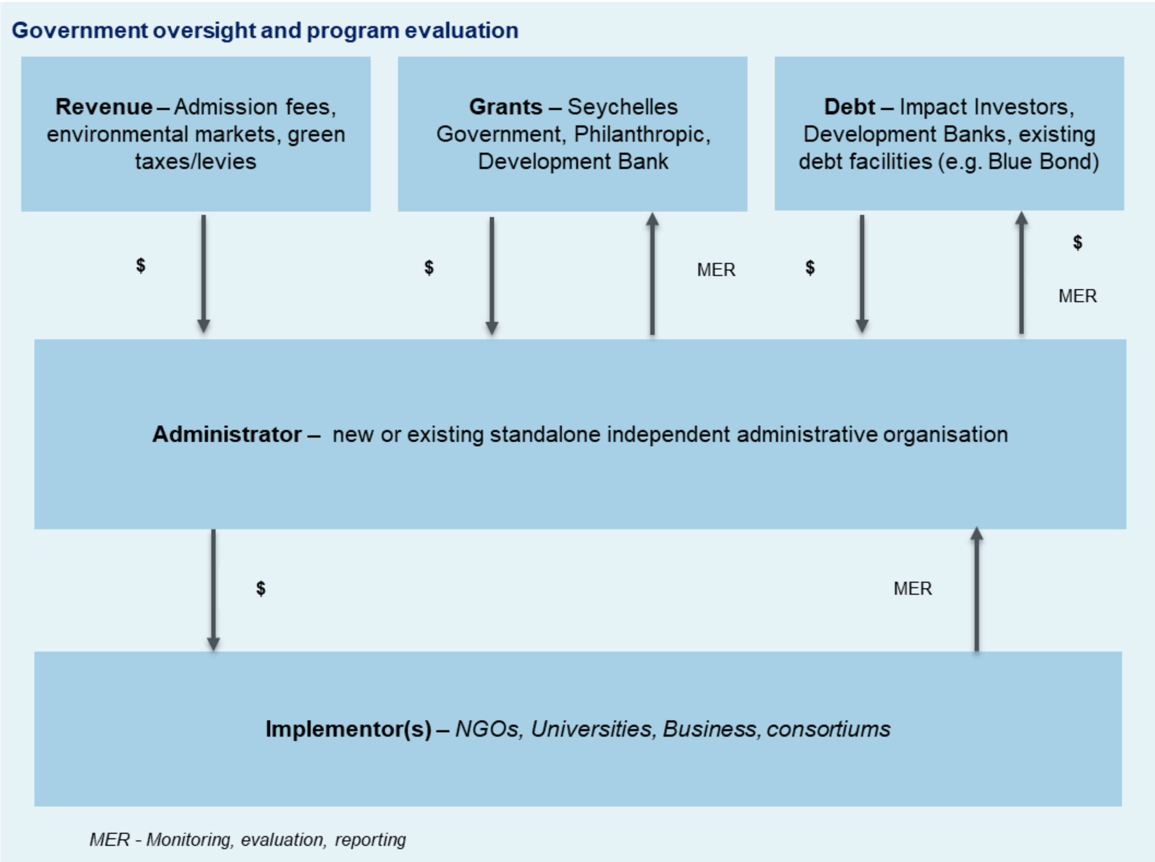


Figure 11-1 High-level summary of governance arrangements

Box 2 – Governance arrangements over time and the role of Government

The governance arrangements for implementing and managing coral reef restoration will change over time. This business case focuses on the implementation phase of the coral reef restoration program; however, it is important to note that governance arrangements will change as the project progresses. Specifically, the Seychelles Government will need to provide a broader range of roles and responsibilities than identified in Figure 5 during the development, initiation and evaluation phases of the program.

The roles and responsibilities of the Seychelles Government would include:

- Strategy and planning – Government would complete the development of the program strategy and plan its implementation. This would enable the proposed program administrator to focus on managing its implementation.
- Funding due diligence– Government may be required to support the due diligence process prior to any private or philanthropic investment, including funding (or obtaining funding through a grant) for any necessary studies.

During the delivery of the program, the Seychelles Government may also be required to:

- Collect and allocate revenue – Government may be best placed to collect revenue (e.g. the discretionary portion of the CSR tax) on behalf of the program, and provide to the program administrator to repay any debt used to finance the project.
- Be guarantor - Government be required to provide guarantees for the take of live corals from the nursery if it is established as a standalone venture.
- Provide contingency ownership guarantees – Government would likely be the provider of last resort for the program, for example, if the program administrator is no longer able to administer the project.

At the conclusion of the 20-year program, it is proposed that ownership of the restored coral reef assets created would be transferred to Seychelles Government. The transfer of ownership would be dependent upon a range of criteria, which would need to be negotiated with Seychelles Government and other project partners. This model of asset creation, management and transfer (e.g. build, own, operate, transfer or ‘BOOT’) is frequently used in infrastructure public-private partnerships.

Government may be supported to undertake some of these roles. TNC, for example, has provided substantive support to the development of the DfNS and Blue Bond projects. Development banks also typically play a significant role to support many of these roles and responsibilities of Government.

11.2.6.1 Administrator

The program would benefit from the use of an environmental trust fund to ensure that the funds allocated to the program are administered appropriately. Seychelles has two existing environmental trust funds and Aither understands that one of these – the Environmental Trust Fund – will be closed by Seychelles Government with no new environmental trust funds are proposed. While an alternate organisation is being developed through the MSP project (the Seychelles Ocean Authority), an example of an administering organisation is the Conservation and Climate Adaptation Trust of Seychelles (SeyCCAT). Consequently, SeyCCAT has been used as an indicative example of an administrative organisation to inform the development of the business case and is consequently referenced throughout this section. However, any such decision to use SeyCCAT has not been made. The most appropriate administrator will be dependent upon the final strategy and financing arrangements. However, the use of a trusted, well organised and independent organisation as the administrator has been demonstrated to be important to the success of similar programs globally.

SeyCCAT was established through an Act in 2015 and provides a range of services for a fee. The services SeyCCAT provides can be negotiated to ensure the appropriate range of services are provided for the program. SeyCCAT has an excellent reputation and a high-level of governance, including transparent decision-making. SeyCCAT's organisational objectives align with the ambitions of this program, most notably its objective to: Promote the restoration of marine and coastal habitats and ecosystems that have been degraded by local and global impacts.

SeyCCAT would be used to administer the funds made available through government, impact investors, philanthropic sources and development banks. SeyCCAT would release expressions of interest with clearly defined eligibility criteria to ensure appropriate parties could deliver the specific priority projects. The coral reef nursery arrangement described in Section 11.2.5 means that the coral reef restoration would be implemented over a period of at least six years. This arrangement allows SeyCCAT to release an expression of interest yearly or, preferably in order to limit delivery risk, release an expression of interest for groups of priority projects. An expression of interest approach is considered preferential as it is the existing process used by SeyCCAT. For example, this program could be included under the normal blue grants fund process if the timeline is acceptable.

Importantly, the business case identifies SeyCCAT to be the default owner of the new assets created (e.g. coral reef nursery and artificial reefs) for the duration of the program (20 years). It is proposed that ownership would be transferred from SeyCCAT to Seychelles Government at the conclusion of the program. This approach provides for a consistent basis of coral reef restoration development and management, enables a single entity – SeyCCAT – to take out all necessary insurances and will provide the necessary rigour to implement a program in Seychelles. However, this is a significantly different role for SeyCCAT and would therefore need further detailed investigation to ensure this approach is feasible.

Specifically, SeyCCAT would provide:

- Priority project feasibility technical review – SeyCCAT has an existing technical committee, however specific technical skills sufficient to assess coral reef projects would be required (if not already present). SeyCATT currently uses impartial technical observers to assess applications and a similar approach could be undertaken for coral reef projects.
- Evaluation and auditing of priority projects – SeyCCAT would be responsible for monitoring and evaluating the performance of each project funded by the program. Monitoring and evaluation would not need to be undertaken by SeyCATT directly, but could include the use of external consultants. It is important to note that clear guidance on the selection and evaluation of the projects funded by the program would be required to ensure that a national program can be implemented and different projects compared equitably. The high-level performance and monitoring plan identified in Section 11.2.10 could be used as the basis for measuring individual

project performance. The evaluation of the success of the overall program would be separate to this arrangement (see the section on Evaluator, below).

- Administration of funds and revenue distribution - SeyCCAT would administer the financing arrangements. This would include the collection of specific revenue streams which are used to repay the loans and other costs required for the financing and ongoing management of the program.
- Release of project funding – SeyCCAT would release funds to the implementing party(s) in accordance with agreed milestone payments.
- Communication and marketing – SeyCCAT would be responsible for eliciting proposals of sufficient quality from implanting parties, which would require communication and marketing of the program. Given the size of the program and likely efficiencies provided by large-scale opportunities it is recommended that a broad, international marketing campaign is undertaken. Criteria for applications could be weighted towards using local providers as part of the consortium, for example.
- Stakeholder engagement – SeyCCAT would be responsible for stakeholder engagement activities with a focus on ensuring collaboration and alignment across different projects being implemented (for example, MSP and Blue Carbon). Stakeholder engagement would include a strong role for Government, particularly in the development phase of the program.

The delivery of these services by SeyCCAT would require discussion and negotiation on the best approach and the cost of the service. We have assumed that SeyCCAT would require 15 percent of the total funds administered, however this assumed fee is subject to discussion and negotiation. The existing capacity of SeyCCAT to manage this program would need to be further assessed, however the size of the program funding is similar to other programs being administered by SeyCCAT. None-the-less, the discussion and negotiation with SeyCCAT on the final approach and costs of service would include a discussion on what additional supporting resources would be required. For example, there may be additional needs related to MER and communications, as well as a dedicated projected manager to oversee the activities required of SeyCCAT for this program, which are not included within the standard SeyCATT fee.

11.2.6.2 Implementor

An expression of interest process will determine the organisation(s) responsible for the delivery of the individual coral reef restoration projects. However, it is highly likely that NGOs currently operating in Seychelles would be the most likely implementing organisations. NGOs that have successfully delivered coral reef restoration in Seychelles include Marine Conservation Society Seychelles, WiseOceans and Nature Seychelles. In addition, universities (such as University of Seychelles) and private businesses may also be likely implementing organisations.

Given the large size of the program and the capacity and capability requirements for its success, it is recommended that preference is given to a consortium of implementing parties to provide the required services. This would reduce risks for the delivery multiple projects around the Seychelles within a short timeframe including the development of large nursery facilities. A consortium approach has been used previously for coral reef restoration in Seychelles. If a consortium is selected, the consortium would need to be assessed to ensure there is capacity and capability to deliver the program for each key activity as well as appropriate governance arrangements. The consortium could include NGOs, universities and other businesses, for example local hotels and tourism businesses. Further discussions with potential consortium partners identified (e.g. NGOs operating in Seychelles) on how such an arrangement may be best structured, or would be most feasible, would be required to further test and refine this approach.

11.2.6.3 Evaluator

Evaluation of the success of the overall program would need to be undertaken, in addition to the evaluation of each individual project funded by the program. An evaluation of the overall program would need to be undertaken by an independent evaluator, most likely sourced by Seychelles Government and/or development banks or other providers of capital. Evaluation would need to occur at the conclusion of the program (20 years) as well as at agreed times during the delivery of the program, for example, every four years. The cost of the independent evaluator would need to be considered within the total program costs but would likely be paid for separately by Seychelles Government and/or development banks, consistent with their program oversight role.

The proposed ownership and transfer model would require specific milestones to be achieved prior to the acceptance of ownership to Government at the conclusion of the program.

The evaluator would assess a range of program performance criteria, including:

- Whether the outcomes and benefits of the coral reef restoration are being achieved (e.g. as specified in the high-level performance and monitoring plan in Section 11.2.10;
- The appropriateness and efficiency of the program’s activities to achieve the specific outcomes; and
- The appropriateness of the program’s governance arrangements whether the program is likely to deliver a lasting impact.

La Passe – Governance Arrangements

The governance arrangement for the case study on La Passe would require the same key elements as described for the Seychelles program. The key difference when considering the smaller scale and discrete focus of the La Passe case study is the need for clear input and guidance from businesses and residents on La Passe.

The governance arrangements for La Passe would need to reflect the revenue streams, which would be generated on La Digue. Revenues could include consolidation of the CSR tax withheld by local businesses and a visitor’s fee (see Section 11.2.8 for more detail). This could be achieved by forming a representative advisory sub-committee or similar that is enabled to receive monitoring and evaluation reports as well as provide input to the strategy and planning stage. However, it would be appropriate for an administrator technical committee to retain the decision as to the most appropriate use of the funds and their administration to ensure an independent and transparent decision-making process.

11.2.7 Cost Structures

11.2.7.1 Key Activities

The costs for each of the key activities required to implement the program are provided in Table 11-4. A range of assumptions, described below, that have been used to provide a high-level estimate of the potential costs of reef restoration across the Seychelles. It is understood that a range of NGOs have various approaches to coral reef restoration and costs as a result. Our approach has been based upon input from our project team (MCSS and WiseOceans). The costs provide a clear potential, indicative cost to inform the feasibility of this approach. Further refinement, including input on exact costs for different sites and approaches would be important to refine the estimates and assumptions used.

The costs are calculated to restore 15 sites across the Seychelles, with nine sites on Mahe, four on La Digue and Praslin, and one each at Grande Seour and Petite Seour. It is assumed that a 15,000-fragment land-based nursery is established on Mahe and a 5,000-fragment land-based nursery on either La Digue or Praslin. Two 5,000-fragment ocean-based nurseries are also established, one at either Grande Seour and Petite Seour, and one at Baie Ternay. These assumptions are based on achieving rapid coral reef restoration at multiple sites around the Seychelles, however there has been no further assessment of technical feasibility.

At three of the priority project sites (Baie Ternay, Grande Seour and Petite Seour) direct coral transplantation is assumed to be undertaken. At all other sites a hybrid approach is assumed. For the hybrid approach two different methods are costed. The first uses coral friendly concrete modules of ‘Tecno’ reef type design, linked with two lower modules and one upper module with corals at a density of 3 per m^2. The second uses a welded steel frame tunnel of 2 m width and 1 m height with corals at a density of 10.5 per m^2 of sea-bed (due to vertical layering).

Given limited data, no assumption has been made around the impacts of coral bleaching events, however this should be considered when more detailed site-based studies are undertaken. For example, under an assumption that coral bleaching events occur once every five years and kills 50 percent of the corals, the total upfront costs would be over 30 percent higher than under the current analysis.

Upfront capital costs are expected to be incurred over a six-year period from the project implementation. Any costs associated with financing and insurance are excluded. The estimated range of costs for the coral reef nurseries do not include potential economies of scale that may be generated through the proposed approach in this business case.

Detailed cost method and assumptions are provided in Appendix F and Appendix G.

Table 11-4 Summary of upfront and ongoing activity costs

Key activities	Cost type	Estimated range of costs (USD 2019)
Establish and manage coral reef nursery	Upfront capital	$3.0 – $8.6 million
Site-specific project design, including use of artificial reef	Upfront capital	$1.7 - $2.4 million (assumed at 10% of total capital costs)
Implementation of coral reef restoration, including construction, transplantation and algae removal.	Upfront capital	$13.7 – $15.7 million
Total upfront capital requirements		***$18.4 - $26.7 million***
Management of rehabilitated coral reef (including monitoring)	Ongoing	$1.2 - $1.6 million per annum
Program administration – including: Governance and administration; Marketing, communication and stakeholder engagement; Monitoring, evaluation and reporting (MER)	Ongoing	$0.1 - $0.2 million per annum (assuming SeyCATT administration fee 15% of total upfront capital spread over 20-year period)
Total ongoing costs ***(Excludes financing costs i.e. debt repayments)***		***$1.3 – $1.8 million per annum***

La Passe – Cost Structures

The costs identified for a specific coral reef restoration project to be undertaken at a La Passe assumes hybrid reef restoration is undertaken with either concrete or steel structures, and, a single small-scale, land-based nursery is built on La Digue. The costs include:

- Establishing and managing coral nursery (land-based): $125,600 - $397,850
- Site-specific project design: $72,280- $107,905 (assumed to be 10 percent of total capital costs)
- Implementation of coral reef restoration: $597,200 - $681,200.

The total upfront cost at La Passe is therefore assumed to be between $725,150 - $1,085,775, with ongoing management including monitoring of between $48,000 - $63,600 per annum.

The range of costs is driven by the choice of artificial reef structures. Using concrete structures is cheaper but has a much lower coral density and therefore reduced benefits compared to the more expensive steel structures.

11.2.7.2 Supporting Activities

There are a range of supporting activities that need to be undertaken to implement large-scale coral reef restoration across the Seychelles. Important supporting activities that would need to be undertaken include:

- Management of exclusion zones and no-take areas around the coral reef restoration sites;
- Management of sediment and nutrient runoff in coastal areas surrounding the coral reef restoration sites;
- Management of aquaculture activities that may impact on the coral reef restoration sites;
- Development of an Environmental Impact Assessment prior to implementation; and
- The collection and sharing of data and information amongst relevant stakeholders.

The success of delivering these activities requires sufficient support from the relevant delivery partners and the development of relevant plans and policies, such as Marin Park Management Plans. As described in Section 11.2.5, the status of the relevant plans and policies is variable.

The supporting activities will be being undertaken through other processes and therefore would not present direct costs to the program. Consequently, it would be reasonable to expect that the supporting activities would be delivered through what can be classified as in-kind contributions to the program. However, it will be important that the final prioritisation of sites is aligned with the capacity and capability of the key supporting partners to undertake the supporting activities.

Additional costs may be incurred for the development of the program. In addition to the likely in-kind contributions from Seychelles Government to facilitate program development, these costs include the studies and the costs to undertake due diligence prior to financing. Due diligence costs can be high and consequently it would be important that these costs are paid for by grants (e.g. from Seychelles Government and/or development banks) to attract sufficient interest from private sources of capital as the size of the capital requirement is small, and the expected rate of return is low.

11.2.8 Financing and Revenue Streams

This section of the business case presents a high-level financial analysis of the program, focussed on comparing the costs of the key activities with potential financing options. Sources of revenue and sources of capital are assessed, including an analysis of different proportions of debt that could be funded by the identified revenue sources.

11.2.8.1 Sources of Revenue

Potential sources of revenue for the program have been identified by assessing the different revenue streams (see Section 11.2.8 and Appendix D) and the beneficiaries (potential customers) identified in Section 11.2.4. A summary of potential sources of revenue, their potential value and level of certainty, risks and constraints for Seychelles is provided in Table 11-5.

The assessment of potential revenue streams has identified that the program could mobilise revenues of approximately $7.3 million per year. However, the majority of the revenue ($6.6 million per year) is dependent upon the use of a green taxes and levies, at least part of which (e.g. a new

Existence Levy) may be unpalatable to stakeholders and Seychelles Government. The Seychelles is generally considered have a range of similar taxes and fees. The revenue from these are also sought after for a range of initiatives - such as waste management. The prioritisation of these revenue streams for this strategy would be important if these sources of revenue were to be available. Only $0.7 million per year is available from other sources, excluding revenues sources that have relatively low certainty and high risk. Consequently, the assessment does not include potential revenue from voluntary donations (which are highly unpredictable) or potential revenue that could be generated by the establishment of the nurseries as standalone businesses or skills export markets. These options should be further explored in order to better understand the opportunity they may present.

The sources of revenue required will also be dependent on the scale of coral reef restoration being undertaken, as well as the likely beneficiaries. For example the use of parametric insurance products such as those used in Mexico may be more appropriate to highly concentrated beneficiaries (e.g. hotels). The conditions for this are less obvious in Seychelles due to the lower density of development.

Box 3 – Carbon Sequestration

Whilst carbon sequestration in mangroves and seagrasses has been identified as a potential avenue for selling carbon credits and generating revenue, this is still a relatively new area in carbon financing. There is limited experience in using carbon sequestration, in particular blue carbon, as a source of revenue for coral reefs. There is significant current interest however and is likely to become more feasible in the near future. One such example identified through this project was through the expansion of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The implementation of CORSIA is likely to drive significant increases in demand for carbon offsets and Seychelles, if it being a partner to CORSIA, could benefit from this increased demand.

An example where carbon sequestration has been used to generate carbon credits is the carbon farming initiative (CFI) in Australia. The CFI is an Australian Government scheme that allows farmers and other land managers to earn Australian Carbon Credit Units (ACCUs) by reducing greenhouse gas emissions or storing carbon (also known as carbon sequestration) in the landscape. These ACCUs can be sold to people and businesses wishing to offset their emissions. The CFI also helps rural communities and the environment by supporting sustainable farming by creating incentives for landscape restoration. The CFI includes an environmental plantings methodology determination, which covers the establishment and management of permanent native forests through the planting and/or seeding of native species on cleared or partially cleared land. This achieves greenhouse gas abatement by removing carbon from the atmosphere and storing (sequestering) it in trees by growing a native forest.

Table 11-5 Summary of potential revenue sources

Revenue source	Description	Potential value per year and over project lifetime	Certainty, risk and constraints
Admission fees for protected area or high-value, high-use area	An admission fee is currently charged for visitation to national or marine parks. Areas where restoration is undertaken could be designated in a similar way, and entry fees charged.	\$0.3 million /year (assuming \$15 per visit, 20,000 visits across all new sites)	Medium certainty, medium risk. Tourists currently pay \$15 per visit to other national and marine parks in Seychelles. If areas with restoration are designated the same way tourists should be willing to pay to visit. However, it is unclear whether it is possible to designate this number of sites and what the number of visitors may be. There may be an overlap with admission fees charged by SNPA for some sites.
Environmental markets	Carbon sequestration benefits can be quantified and sold as carbon credits into existing markets or through corporate responsibility programs	\$0.4 million per year (assuming carbon price of \$10/tCO2e)	Medium certainty, high risk. Carbon credits could provide an ongoing revenue stream, however there is currently limited data on the extent of seagrasses and mangroves in the Seychelles[4].
CSR tax	0.25% discretionary CSR tax	\$5 million per year	High certainty, medium risk. Discretionary CSR revenue should be relatively consistent over time and is already collected for use on environmental projects. There may be resistance to use the CSR tax for the program, or the CSR tax may be restricted for being used on environmental projects in future.
Existence levy	Payment by tourists towards coral reef restoration	\$0.6 million /year (assuming levy of \$2/tourist entering Seychelles)[5]	High certainty, low risk. An existence levy could be collected from all tourists as part of other fees paid on entry to Seychelles. If the levy is kept low there should be minimal risk.
Green tax	Payment by residents that is collected and	\$1 million / year (assuming a 0.5% increase in sales tax rate)	High certainty, low risk.

[4] Aither understands a project designed to understand the blue carbon potential of Seychelles will commence in the near future.

[5] A willingness to pay study is currently under development which indicates that this assumption may be quite low, with typical values being as high as \$10-\$40. However, not all this revenue may be attributable to the coral reef program.

Revenue source	Description	Potential value per year and over project lifetime	Certainty, risk and constraints
	channelled directly to coral reef restoration		Could be collected through existing tax structures. May be politically unpopular, unfeasible for government.
Voluntary contributions (donations)	Voluntary contributions in the form of donations from tourists and residents alike.	Unknown	Low certainty, high risk. Could be collected from crowd sourcing or other mechanisms. This source of revenue is unpredictable and considered too high risk to rely on for this program given its scale and duration.
New business ventures	As described in financing, it would be possible to establish a centralised nursery as a standalone business venture which included educational, tourism and export facilities.	Unknown	Low certainty, high risk. This would require a feasibility study. It is likely that it would only be feasible if a take or pay contract for supplying the coral to the program or other coral reef restoration programs in the region was established.
TOTAL		**$7.3 million / year**	

11.2.8.2 Potential Sources of Capital

The program would be eligible to receive capital from a range of sources, consistent with the financing assessment framework provided in Section 11.2.8 and Appendix C. The key findings of the assessment in consideration of this program are provided in Table 11-6.

The financing assessment of this program identifies that the program could successfully attract suitable private sources of capital, such as concessionary debt from impact investors and philanthropic grants. However, it would be unlikely that commercial debt markets could be accessed.

Table 11-6 Financing assessment and identification of potential sources of capital

Criteria	Value/option	Summary and implication for sources of capital
Investment size/capital requirement	Small (<$25 million)	Highly unlikely that commercial debt markets could be used to fund the program Access to private debt markets (likely concessionary debt) or grants most likely option
Financial return	Calculable and demonstrable	Distinguishable revenue streams include admission fees, green taxes/levies and environmental markets Access to private financing (concessionary debt) possible based on assessment of program outcomes and available revenue streams
Return on investment timescale	Medium-term (5-20 years)	Assumed that the project delivers returns over a period of 15-20 years, which would be suitable for a debt product
Insurability	Insurable	New assets created by the program are possibly insurable, specifically through the use of alternative insurance products, such as parametric insurance
Program attribution to achieving social, economic or environmental outcomes	Certainty on outcomes and their relationship to the activities of the program	Program provides a range of demonstrable environmental benefits. Clear attribution would require additional studies to be undertaken, including project feasibility studies. Suitable for impact investors and philanthropic grants, particularly towards priority projects that demonstrate clear biodiversity outcomes
Ownership and governance	Public-private-partnership	SeyCCAT is proposed to be the owner of the program's assets during the life of the program and facilitate all governance arrangements. Suitable for private financing given high standards of governance.

Given the expected avoided infrastructure costs and other benefits to the broader Seychelles community, Seychelles Government could reasonably be expected to provide a grant for the program. Specifically, some portion of the $13 million that has been suggested to implement the Seychelles Coastal Management Plan could fund this program, given the similar outcomes sought. Additional avoided costs to Seychelles Government, such as repairing damage to infrastructure as a result of flooding, also provide a basis for Seychelles Government supporting financing for this program. However, the value of this benefit is yet to be identified.

In addition to grants from development banks and Seychelles Government, a philanthropic grant may also be possible. This would be most likely when a clear biodiversity benefit in areas of high environmental value could be demonstrated. However, the philanthropic grant may need to be distinguished from other capital sources and directed toward restoration at a specific project site. These types of projects would be more attractive to philanthropic capital providers or investors with a biodiversity mandate.

Any debt would need to be sourced through private markets. Similar to other programs, such as DfNS, impact investors would likely be attracted to the program given its biodiversity outcomes. Impact investors may be able to provide debt with a lower required rate of return than commercial markets (concessionary debt). A development bank and/or Seychelles Government could be used to help leverage private debt by de-risking the investment for impact investors, such as by providing a first loss position. It is possible that the existing Blue Bond program in Seychelles could be used to fund smaller projects or some of the program development costs through the provision of a grant and/or debt.

The program should identify and prioritise the use of grant funding (whether from Seychelles Government, development banks or philanthropic sources) and consequently, minimise the debt required. The maximum amount of debt that could be reasonably used to finance the program is highly dependent upon available revenue. A high-level assessment of different debt to grant options is presented in Table 11-6.

Table 11-7 Potential ratios of debt and grants compared to the available revenue sources

	Scenario 1	Scenario 2	Scenario 3
Upfront capital	$22.5 million	$22.5 million	$22.5 million
Grant	$22.5 million (100%)	$11.25 million (50%)	$0 million (0%)
Debt	$0 million (0%)	$11.25 million (50%)	$22.5 million (100%)
Yearly debt repayment at 3% over 10 years	n/a	$1.3 million	$2.6 million
Ongoing management costs per annum	$1.3 million	$1.3 million	$1.3 million
Total annual revenue requirements	***$1.3 million***	***$2.6 million***	***$3.9 million***
Percentage of total revenue available ($7.3 million)	~20%	~35%	~50%
Percentage of total revenue available	~55%	~110%	~170%

	Scenario 1	Scenario 2	Scenario 3
excluding CSR tax[6] ($2.3 million)			

Given the expected avoided infrastructure costs and other benefits to the broader Seychelles community, Seychelles Government could reasonably be expected to provide a grant for the program. Specifically, some portion of the $13 million that has been suggested to implement the Seychelles Coastal Management Plan could fund this program, given the similar outcomes sought. Additional avoided costs to Seychelles Government, such as repairing damage to infrastructure as a result of flooding, also provide a basis for Seychelles Government supporting financing for this program. However, the value of this benefit is yet to be identified.

In addition to grants from development banks and Seychelles Government, a philanthropic grant may also be possible. This would be most likely when a clear biodiversity benefit in areas of high environmental value could be demonstrated. However, the philanthropic grant may need to be distinguished from other capital sources and directed toward restoration at a specific project site. These types of projects would be more attractive to philanthropic capital providers or investors with a biodiversity mandate.

Any debt would need to be sourced through private markets. Similar to other programs, such as DfNS, impact investors would likely be attracted to the program given its biodiversity outcomes. Impact investors may be able to provide debt with a lower required rate of return than commercial markets (concessionary debt). A development bank and/or Seychelles Government could be used to help leverage private debt by de-risking the investment for impact investors, such as by providing a first loss position[7]. It is possible that the existing Blue Bond program in Seychelles could be used to fund smaller projects or some of the program development costs through the provision of a grant and/or debt[8].

The program should identify and prioritise the use of grant funding (whether from Seychelles Government, development banks or philanthropic sources) and consequently, minimise the debt required. The maximum amount of debt that could be reasonably used to finance the program is highly dependent upon available revenue. A high-level assessment of different debt to grant options is presented in Table 11-8.

6 Discretionary CSR tax revenue can currently be used for environmental projects, however this revenue is used at participants discretion, and the criteria for projects may change. It may therefore be unlikely to provide a steady source of revenue in its current form.

7 First loss position is a position that will suffer the first economic loss if the underlying assets lose value or are foreclosed upon. This would mean that the development bank and/or Seychelles Government would provide a guarantee of priority to the repayment of other creditors.

8 It may be possible that the program could access grant funding from the Blue Bond project to develop a specific priority project business plan, the applicant could subsequently apply for a grant.

Table 11-8 Potential ratios of debt and grants compared to the available revenue sources

	Scenario 1	Scenario 2	Scenario 3
Upfront capital	$22.5 million	$22.5 million	$22.5 million
Grant	$22.5 million (100%)	$11.25 million (50%)	$0 million (0%)
Debt	$0 million (0%)	$11.25 million (50%)	$22.5 million (100%)
Yearly debt repayment at 3% over 10 years	n/a	$1.3 million	$2.6 million
Ongoing management costs per annum	$1.3 million	$1.3 million	$1.3 million
Total annual revenue requirements	***$1.3 million***	***$2.6 million***	***$3.9 million***
Percentage of total revenue available ($7.3 million)	~20%	~35%	~50%
Percentage of total revenue available excluding CSR tax[9] ($2.3 million)	~55%	~110%	~170%

For the range of options assessed in Table 11-8 it is apparent that with the inclusion of CSR tax revenue the program could be wholly financed through a concessionary debt approach. However, if CSR tax revenue was not able to be used to finance repayments, the program would need to either identify additional sources of revenue such as new export opportunities or business ventures, or secure additional grant funding to reduce the cost of debt repayments.

Implementation of the program could also be undertaken through a mix of financing sources for specific purposes. For example, private debt could be used for the upfront capital components of the projects while a grant could be invested to provide an annuity payment that covers all or a portion of the ongoing operational and financing costs. A similar arrangement has been successfully deployed for the DfNS. Alternatively, financing for discrete activities as a standalone business unit could be undertaken – an example of this approach is described in Box 4 – Coral reef nurseries – separate financing strategy.

It is important to note the conclusion of the assessment undertaken in this section does not include recognition of the full range of potential social, economic and environmental benefits. Recognition and valuation of these benefits (through further detailed studies), as more fully described in the Task 2 progress report and Section 11.2.4, should be encouraged as they can be used to identify and attract potential grants from other sources and additional sources of potential revenue.

9 Discretionary CSR tax revenue can currently be used for environmental projects, however this revenue is used at participants discretion, and the criteria for projects may change. It may therefore be unlikely to provide a steady source of revenue in its current form.

La Passe – Revenue Streams

Revenue streams for La Passe are likely to be similar to the wider approach for the Seychelles, although there may be lower potential for CSR contributions given the smaller scale of many of the hotels and tourism operators compared to Mahe. Some potential revenue streams that have been identified include:

- Admission fees for protected area or high-value, high-use area: This could generate $22,500 per year assuming 1,500 visitors at $15 per person.
- Environmental markets: Carbon sequestration benefits of seagrasses in the area could potentially generate $24,280 per year assuming a carbon price of $10/tCO^{2}e
- Existence levy: Given the value tourist place on the beaches of La Digue, as well as on other environmental outcomes, a visitor levy of $2 per person could be charged which would generate approximately $160,000 per year.

These revenue streams would likely be sufficient to support both ongoing management costs, and repayment of debt financing for the upfront capital requirements at 3 % p.a. for 10 years. Reductions in upfront costs through grant funding (for example through the coastal management plan activities), would help to further reduce the risk and revenue requirements.

Box 4 – Coral Reef Nurseries – separate financing strategy

The delivery of the program at the sites prioritised for coral reef restoration across Seychelles (see Appendix F) requires a significant number of coral fragments. This business case has assumed that the implementation of the coral reef restoration would occur within six years (further assumptions are provided in Box 1). To accommodate this timeline, multiple large-scale nurseries are required. In addition, the sites prioritised for coral reef restoration (see Appendix F) are located throughout the Seychelles. Consequently multiple, larger nurseries are proposed as part of this program. Aither understands that a separate regional project will commence in August 2019 investigating the potential for coordinating coral reef restoration activities in Seychelles and Mauritius, which will include investigating this concept. This should provide timely information on the feasibility of this approach.

It may be possible to distinguish the costs and revenues related to the nurseries and establish a separate stand-alone business entity. The nurseries have a clear and demonstrable revenue base over six years (live corals). This feature, if appropriately dis-aggregated from the remainder of the program, may enable the coral reef nurseries to be financed from private sources. Alternatively, the nurseries could be identified and marketed as a government-supported business venture for the private sector and others (including consortiums) to bid for. This approach would require the competing parties to identify funding streams to support the venture.

Establishing the coral reef nurseries as a separate business unit would enable third parties to identify innovative approaches to running the nurseries and reduce the need for the nurseries to be financed as part of the overall program.

11.2.8.2.1 Funding for Supporting Activities

The development of the program through to implementation requires a range of development costs. These costs include feasibility studies and any due diligence costs that may be required to attract financing for the capital and ongoing costs of the program. Program development costs would need to be funded through a grant – such as from Seychelles Government or a development bank – which is a fairly common and appropriate source of funds. For this program it is particularly important that the development costs are funded as the required size of the required capital is small and consequently it is unlikely a private investor would be willing to invest significant time and money into a due diligence process.

Funding to pay for the key supporting activities (such as restricting access to the priority project sites) is most likely to occur through in-kind support from the key partners. However, potential sources of revenue do exist for Seychelles Government to help offset any additional costs. For example, through biodiversity offsets (considered as a ‘green tax/levy’).

11.2.9 Strategic Risks

Strategic risks are those risks that may inhibit the delivery of the outcomes and benefits of the program. This section outlines strategic risks for the success of the program. Table 11-9 provides a summary of potential strategic risks, followed by a more detailed description of the impact of climate change and the importance of stakeholder engagement. Mitigants for these risks will include various insurances, as well as advocacy and stakeholder engagement. It should be noted that coral reef restoration as an activitiy is highly uncertain. The restoration works may not provide all of the benefits expected, or to the same levels as estimated. Further, coral bleaching and other external impacts (detailed in the table) can greatly limit the effectiveness of the program. Ongoing research and adaptive management will assist in minimising these risks.

Managing strategic risk benefits would also benefit from the use of adaptive management. Adaptive management recognises that the environment in which the program operates may change over time. The most appropriate management action may need to change in response. To use adaptive management effectively, it is important to implement a clear performance and monitoring plan (see Section 11.2.10 for more information) to evaluate the success of the program and identify whether changes need to be made to its implementation.

Table 11-9 Summary of strategic risks

Risk	Description
External	Climate change resulting in detrimental impacts to the restored coral reef (increased ocean temperature, increased acidity and disruptive weather) Crown of thorns starfish causes detrimental impacts to the restored coral reef Adverse interaction with other activities: Upstream activity increases nutrient or sediment run-off Change in management actions used to mitigate external impacts (e.g. government policy on accessing the reef reduces tourism benefits) Change in marine activities (e.g. new aquaculture activity) Ineffective stakeholder engagement Failure of activities delivered by key partners

Risk	Description
Government and regulatory	Change in compliance standards or environmental compliance policy Change to policy on carbon, biodiversity or other potential environmental markets
Operational	Governance and accuracy of delivering of the program at scale (OH&S, materials, engineering, etc...) Increase in cost of materials, labour or other key input costs Land access for coral reef nursery
Financing	Inadequate communication of benefits and risks to potential funders (government, philanthropic/mission-driven investors/wholesale debt markets) Commercial viability – immature/underdeveloped environmental markets, risk and returns do not meet investor requirements Failure of environmental markets Change in focus of investment mandate of impact investors or philanthropic partners Government unwilling to use fiscal policy (tax) to fund the project
Technological	Acceptance of different coral species (e.g. more resilient to higher temperatures) Development of new hybrid structures

11.2.9.1 Climate Change

Climate change represents a significant strategic risk to the success of the program. Climate change will lead to an increase in likelihood and severity of coral bleaching, increased acidity or large storm events that would destroy the rehabilitated live corals, having a significant impact on the overall success of the project. Coral bleaching events in particular are predicted to become more frequent in the next 20 years. The effect of this could be significant. For example, assuming bleaching events occur once every five years and destroy 50 percent of corals increases costs by over 30 percent. However, if coral bleaching reached 90 per cent every five years these costs would increase by over 100 per cent.

The use of artificial reef structure will reduce the impact of such events on addressing coastal erosion and flood. However, without live corals the full-scale of these and other benefits would not be achieved.

11.2.9.2 Stakeholder Support

Community support will be important to allow for the program to be successful. For example, a coral reef restoration project proposed in the North East of Mahe, which also proposed artificial reef structures, demonstrated that residents may be opposed to the deployment of man-made structures onto natural remanent coral reefs. The development of the coral reef policy will further inform the approach that is deemed appropriate across Seychelles.

Aither understands that there has been significant push-back on the principle of introducing new or increased levies/fees on tourists or directly on hotels and tourism-related businesses. In addition, the use of the discretionary component of the CSR tax by hotels may be difficult to coordinate at a national level. To leverage the CSR tax, hotels and tourism industry will need to have buy-in to the proposed program, which requires them to voluntarily provide the CSR tax to contribute to funding the program. Alternatively, this can be regulated, including directing how the CSR tax that is consolidated to Seychelles Government is used. The consolidation of the CSR tax would allow for a substantive revenue stream for the project.

La Passe – Strategic Risks

The strategic risks highlighted for the project are consistent with those that may be experienced on the project at La Passe. Of particular note, stakeholder support would be critical to the success of the project when the primary form of revenue is the CSR contribution from businesses on the La Passe or where a visitor fee is introduced. Without regulation (which would be unlikely), both of these potential revenue streams would need to supported by local residents and businesses.

11.2.10 High-level Performance and Monitoring Plan

An appropriate performance and monitoring plan is essential to develop an understanding of whether the program is functioning as expected and achieving its stated outcomes. A performance and monitoring plan can help to answer questions such as:

- **Are deliverables appropriate and being achieved?** For example: is the coral reef nursery providing sufficient supply of quality coral to meet program requirements? Is the process of live coral being transportation and installation successful?
- **Are outcomes are being achieved?** For example, when compared to the agreed baseline: is there a measurable reduction of wave runup and increase in biodiversity?
- **Do the strategic risks remain plausible and are affecting the outcomes as anticipated?** For example: are the number of coral reef bleaching events within the scenario used for the cost modelling? Has there been any change in the technology that could assist with implementing the program?

Establishing a baseline and monitoring the key indicators that help answer these questions allows for the program to be effectively evaluated and adapted if required (see Box 5 – Adaptive Management, below). A high-level performance and monitoring plan is presented in Table 11-10, which would be similar to that required for the case study project on La Passe. The specific metrics (baseline and targets) would need to be determined in accordance with each restoration site chosen and the final agreed approach to restoration. For example, if the artificial reef structure uses concrete the coral cover is 3 colonies per m^2, whereas if a steel structure is used the coral cover will be 10.5 colonies per m^2.

The high-level performance and monitoring plan is developed to be clear and simple, allowing for a focus on the most important on understanding whether the outcomes are being achieved. For example, is there a measurable reduction of wave runup when compared to the agreed baseline. This focus provides for a high-level understanding of whether the program is successful based on the assumption that if, for example, the coral is not being supplied or is being destroyed by bleaching events than the expected benefits of the program would not be achieved. Additional studies to understand the agreed baseline will be required.

It would be possible, however, to further develop the high-level performance and monitoring plan to focus on key supply chains, risk, financing or other indicators. This approach would provide a more comprehensive and detailed performance and monitoring plan that could be used by SeyCCAT to inform their reporting on the success of the program to government, financiers and other key stakeholders (e.g. community and business groups). This would be complementary to the specific reporting requirements that financiers, for example, may have e.g. related to grant or loan covenants.

Box 5 – Adaptive Management

If the performance and monitoring plan is used effectively it will allow for an adaptive management approach to be undertaken. Adaptive management is important as it allows for the most appropriate action to be undertaken, in response to a change in the system (or understanding of the system) in which the program is implemented. Adaptative management includes the following steps:

- Setting clear outcomes
- Linking knowledge (including local knowledge), management, evaluation and feedback over a period of time
- Identifying and testing uncertainties
- Using management as a tool to learn about the relevant system and change its management
- Improving knowledge.

The performance and monitoring plan outlined in this business case provides the basis for this approach to be used.

Table 11-10 High-level performance and monitoring plan

Outcome	Indicator	Measure	Baseline and target	Data sources	Collection frequency
Wave-run up is reduced at relevant priority sites	Reduction in beach erosion	Number of beach erosion events M3 sand per event	Site dependent (TBC to be determined in specific priority project business case)	Site monitoring by project implementor	Annually
	Reduction in flood events	Number of flood events Extent of flood event	Site dependent (TBC to be determined in specific priority project business case)	Site monitoring by project implementor	Annually
Biodiversity increases at relevant priority sites	Increase in coral cover	M2 of coral cover	Site dependent (TBC to be determined in specific priority project business case)	Site monitoring by project implementor	Monthly
	Increase in biomass	Number and species of marine flora and fauna: number of herbivorous fish, by species number of non-herbivorous fish, by species number of urchins, by species extent and health of seagrass meadow	Site dependent (TBC to be determined in specific priority project business case)	Site monitoring by project implementor	Quarterly
Visitation increases at relevant priority sites	Increase in number of visitors	Visitors per year	Site dependent (TBC to be determined in specific priority project business case)	Seychelles Tourism Department	Annually

12 Summary and Conclusions

This project has demonstrated that there is potential to undertake large-scale coral reef restoration in the Seychelles using innovative financing mechanisms. The business case has been developed in consideration of the key findings from before work in this project. The business case has identified and assessed a path forward for implementing large-scale coral reef restoration in the Seychelles.

The key findings of the project and recommendations for further work to support the business case for large-scale restoration are described in this section.

12.1 Key Findings

There is significant potential to undertake large-scale coral reef restoration in the Seychelles. A prioritisation of potential sites for coral reef restoration identified 15 sites that could be included in a large-scale coral reef restoration project in the Seychelles. The primary objective of the restoration on these sites is reduced wave energy (reduction in beach erosion and coastal flooding), as well as increased biodiversity. The would be achieved through a mix of direct transplantation and hybrid reef modules with coral transplantation. Undertaking coral reef restoration on these sites would result in significant economic benefits, with the highest value being achieved where both coastal protection and recreation/ tourism are primary drivers of restoration.

The size of the upfront investment needed to restore the 15 prioritised sites is estimated to be between \$18.4 - \$26.7 million. The financing assessment of the program identified that the program could successfully attract suitable private sources of capital, such as concessionary debt from impact investors and philanthropic grants. However, it would be unlikely that commercial debt markets could be accessed given the relatively small size of capital required. Ongoing management costs are expected to be approximately \$1.3 - \$1.8 million per annum. The final ratio of capital sources will influence the ongoing revenue requirements of the program. With all grants the ongoing revenue requirements would simply be the yearly management costs (e.g. \$1.3 million). However, with only concessionary debt, the yearly revenue requirement increases by \$2.6 million (e.g. to \$3.9 million) to repay the interest on the loan and the required capital repayments. The costs used in this analysis do not include any assumptions around the likely effects of climate change. For example, a cost increase of over 30 percent would occur if it is assumed that coral bleaching events occur once every five years and cause a 50 percent mortality rate.

The business case found that the 15 priority sites can generate some new and specific revenue streams, which include admission fees, environmental markets, green taxes and levies. The revenue streams assessed would be sufficient to pay \$3.9 million per year, which is the required yearly revenue requirement to pay for the ongoing management costs of the program as well as repayment of concessionary debt financing for 100 percent of the program's upfront capital costs. However, use of 50 percent of the total CSR tax (e.g. the discretionary portion) is required to adequately fund the coral reef restoration in this way.

Without the CSR tax, 50 percent of the upfront capital would need to be funded through grants unless other additional sources of revenue can be identified. This would include new export opportunities or business ventures. For example, additional revenue could be generated by undertaking a separate financing strategy for the coral nurseries. This may allow a private party to finance the development of the nursery business, with Government providing a secure contract for the supply of live corals over the project period. Alternatively, additional grant funding would need to be secured to reduce the cost of debt repayments.

Implementation of the business case is feasible and will be able to leverage existing structures and processes, which would reduce project establishment time, costs and complexity. A trusted, well organised and managed organisation is critical to the successful delivery of the program. Consortiums of NGOs and other partners would likely be required to undertake the coral reef restoration activity, given the scale of the program and the proposed timeframe for implementation (six years).

The business case relies upon a number of key partners to support the program's implementation. For example, the success of the program is dependent upon co-management activities such as reducing nutrient run-off and restricting access to the site while it is being restored. Most notably, project implementation will require significant support from Seychelles Government and development banks. Support would be required to develop the program, provide assurance and support during program implementation as well as to periodically evaluate the success of the program.

There are significant risks to the ongoing viability of coral reefs in the Seychelles due climate change, which needs to be accounted for when this program is implemented. Consequently, the use of adaptive management is important to ensure that the activities undertaken by the program remain appropriate to manage these risks and are able to achieve the program's objectives.

13 Recommendations

- A pilot-feasibility study should be undertaken to underpin the implementation of the large-scale program. This would help to
  - Refine stakeholder engagement required to achieve social licence to operate.
  - Test the potential for achieving integrated finance approaches.
  - Undertake detailed assessment of restoration/hybrid engineering approaches that accord with the values of stakeholders, and which are necessary to achieve desired coastal zone management outcomes in the test location.
- Following successful outcomes from the pilot study, a targeted large-scale coral restoration program should be implemented to fund and manage coral reef restoration activities which can help to deliver coastal zone management objectives in the Seychelles.
- This restoration program should be overseen by an independent body which is responsible for obtaining and allocating funding, driving engagement and implementation and monitoring and reporting on the achievement of outcomes.
- The program should align with policy and program development such as the Coral Reef Policy that is currently under development.
- Alignment with other legislation, policy and management can help to ensure that government organisations which are responsible for addressing other pressures which impact resilience of coral reefs such as catchment runoff (sediment and nutrients), fishing pressure, and tourism related pressures, prioritise and implement actions that are consistent with the reef restoration objectives and activities.
- A component of available funding should be committed to obtaining and developing new knowledge about leading practice in coral restoration to ensure the program remains cutting edge and adopts the most effective methods that can help to obtain long-term outcomes.
- The program should not replace, but should align with and support information exchange with other non-government programs that are focussed on achieving biodiversity outcomes.

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Appendix A The Business Model Canvas

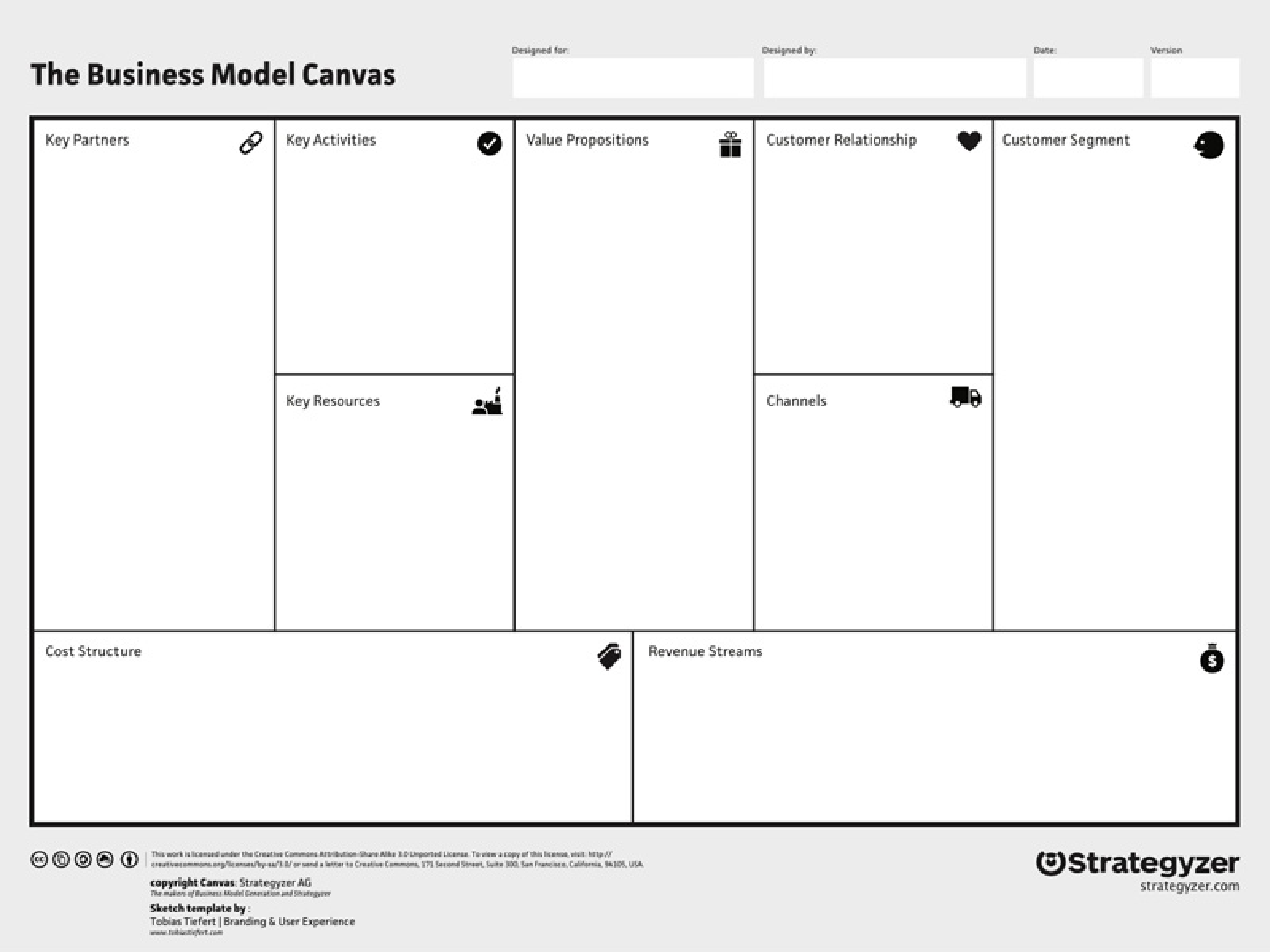

Figure A-1 The Business Model Canvas

Appendix B Business Model Review

A review of coral reef restoration projects has identified key questions that when answered appropriately help inform the development of a business model for coral reef restoration. The following key questions that help achieve this outcome have been adapted from Vertigo Lab (2017):

- Stakeholder and beneficiaries: Which stakeholders comprise the key beneficiary group? What service (benefit) do the service providers offer to the targeted beneficiary group?
- Activities, resources, costs: What are the main activities, partners and resources needed to reach the coral reef restoration objectives? How much funding does it require?
- What sources of financing are most appropriate?

Each of these questions has been considered in the development of the business model, presented in the form of a business case. In addition, the business case presented in this report provides an understanding of strategic risk and a high-level performance and monitoring plan to understand whether the business model used is successful.

A summary of the methodology used to inform the response to each of these questions in this project is discussed below. The methodology used to assess what sources of financing are most appropriate for coral reef restoration is explored in greater detail in Section 11.2.8.

B.1 Stakeholders and Beneficiaries

Identifying the stakeholders that comprise the key beneficiary group, and the benefits they receive, helps to identify potential revenue streams. The identification of appropriate revenue streams is critical to success of a sustainable financing strategy for conservation, otherwise the conservation strategy would need to be funded through grants and donations (the ‘business-as-usual’ approach to conservation).

A key example of this relationship is the parametric insurance business model used in Quintana Roo, Mexico, which relies on the benefit received by the tourism industry from the maintenance of the coral reef. The coral reef protects the beach, which is the primary reason for tourists to visit. The business model works because of the high concentration of similar stakeholders who value the same benefit the reef provides (coastal protection) and consequently have a high willingness to pay for that ecosystem service.

The process of identifying beneficiaries and the benefits they receive can be achieved through using a cost-benefit analysis framework. This work was undertaken in Task 2 of this project and has informed the identification of beneficiaries and benefits, and in-turn, potential revenue streams to fund large-scale coral reef restoration in Seychelles.

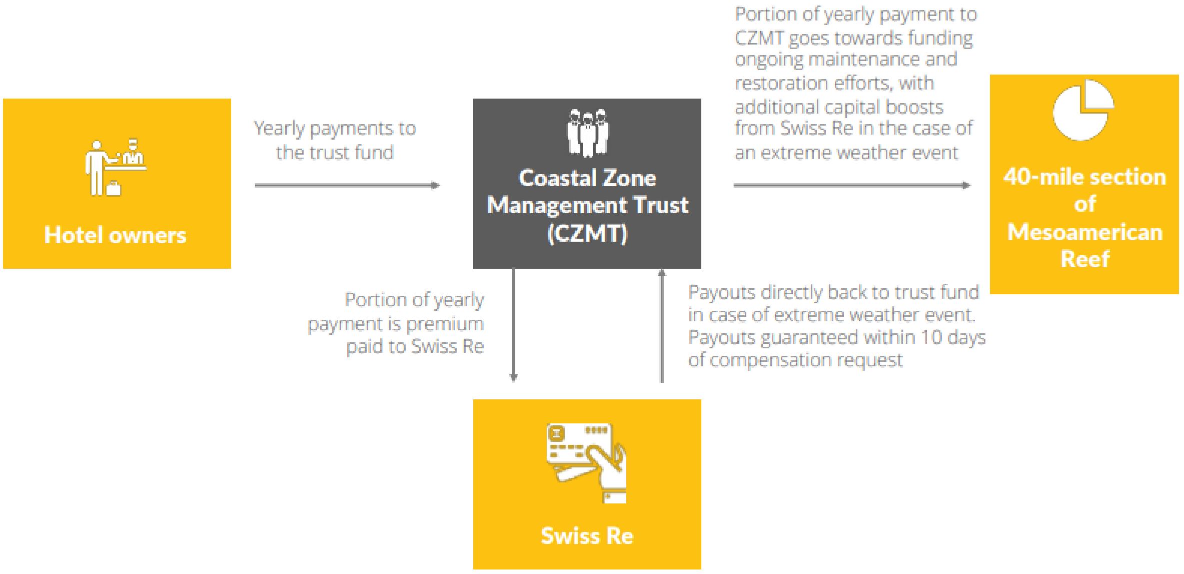

Figure B-1 Generalised framework of Quintana Roo reef insurance scheme (Lyer 2018)

B.2 Activities, Resources, Costs

The key activities, resources and costs required to implement a coral reef restoration business model can be identified through an overview of the generalised framework, or governance arrangements, used for the project. The roles and responsibilities can be broadly identified as administrator, implementor, evaluator and financing. The specific activities, roles and responsibilities for each of these broad categories of governance are described below.

- **Administrator** – the implementation of the project requires an intermediary to administer the project, including the management of sources of capital (e.g. proceeds from bond) and revenue (e.g. proceeds from selling carbon credits). The administrator may also monitor and evaluate project performance for the purpose of reporting to funding organisations and other key stakeholders. The administrator plays a critical role. Many of the business models reviewed use a conservation trust fund, which is a private, legally independent institution entity often developed specifically for the project. The administrator would typically charge a fee to deliver the services required, which need to be clearly identified and agreed. It is possible that some of the administrator services are provided in-kind or through other arrangements, typically with involvement from the relevant local, state or national government or a development organisation.

  According to Ivey 2018, there are over 80 conservation trust funds around the world, either in operation or in some stage of development. Conservation trust funds play a unique role in the conservation space because they are well-positioned to work with government to influence policy and drive national level financing, to influence and educate individuals within their operating sphere, and to partner with other NGOs, on a local, national and global scale. In addition to marshalling financial resources to drive conservation outcomes, they also play a role in bringing together key stakeholders to achieve conservation goals. Conservation trust funds typically bring together a diversified suite of financing mechanisms to address a variety of needs and opportunities, and to avoid overreliance on any one source of funding (Ivey 2018).

- **Implementor** – delivers the key activities of the project. For coral reef restoration projects this would include establishing and managing the coral reef nursery, coral transplantation, coral reef management and monitoring. These roles and responsibilities have often been undertaken by NGOs (for example, the Quintana Roo reef insurance scheme).

  Costs for these activities comprise the vast majority of the cost to implement conservation project. Costs include paying the raw materials (e.g. live corals) as well the establishment and management of the coral reef nursery.

- **Evaluator** – verification that the intervention is achieving its intended benefits. In specific financing mechanisms, most notably pay-for-performance mechanisms such as an Environmental Impact Bond, it is critical the evaluator is an independent third-party. Independence is important because the performance of the project is used as the basis for providing a higher return to investors. However, other financing mechanisms (such as the Debt-for-Nature Swap) do not rely on project performance to this extent. However, each financing arrangement would have specific evaluation and auditing requirements that would need to be undertaken, for example to ensure loan covenants (e.g. cash flow or working capital requirements) are not breached.

  Independent evaluation of the overall strategy is important and would be carried out separately to the other evaluation activities, which may be facilitated by the administrator. Typically, this would be facilitated by the relevant Government, with assistance from development banks or other similar parties.

- **Financing** – provides the capital required to undertake the project. Financing includes the identification of specific revenue streams (such as from the sale of carbon credits, or payment from Government for avoided costs – such as because of lower interest payments in the Debt-for-Nature Swap example) as well as source of capital (such as from bonds and grants). For coral reef restoration, the source of capital is used to fund the upfront capital requirements for project implementation, such as live corals. The identified revenue streams are important to both repay any debt as well as fund administrative or other ongoing costs, such as monitoring of the project.

  At a high-level, many of the business models used for conservation financing require similar roles and responsibilities as described above. For example, in the Quintana Roo reef insurance scheme financing is provided from hotel owners and Swiss Re (specified events only), administration and evaluation are provided by the Coastal Zone Management Trust and implementation delivered by local non-governmental organisations (NGOs). This structure can also be applied to the Debt-for-Nature Swap (DfNS) in Seychelles. In this example, the administrator and evaluator are the Seychelles Conservation and Climate Adaptation Trust (SeyCCAT) and funding is provided to implementors (NGOs) directly from SeyCCAT. In this example, SeyCCAT administers a grants program that allows marine conservation projects to be undertaken in support of achieving the objectives of the DfNS. Financing is provided by impact investors and grant and debt (loans).

  These typical high-level governance arrangements have been used to inform the development of the relevant sections of the business case for this project.

B.3 Supporting Activities and Key Partners

Successful delivery of the business models relies on a number of delivery partners. Most prominent amongst these is the relevant local, state or national government. Government plays a critical role throughout the development and delivery of the business model, including:

- Leading stakeholder engagement and advocacy for the project.
- Finalising the development of the conservation strategy, through until implementation.
- Providing grants and in-kind support, including for the development of appropriate supporting studies.
- Establishing an appropriate policy and regulatory environment.
- Prioritising complementary management activities, such as implementing systems of protection and compliance (e.g. the management of Marine Parks).
- Evaluating the success of the overarching conservation strategy, including its relationship to complementary activities.
- Provide guarantees to relevant financial parties, including as contingency owner of the project.

Government may be supported to undertake some of these roles. Development banks, for example, typically play a significant role to support many of these roles and responsibilities of Government. For example, they may provide financial guarantees to attract investment from the private sector, particularly in emerging and developing economies.

In addition to Government, there may be a range of other important partners. For example, advocacy groups, who will first need to be convinced of the benefits of the strategy, so they are enabled as communication channels to promote the benefits of the strategy to its members. This would be important where, for example, the strategy relies upon new taxes, fees or levies on particular beneficiary groups. A similar level of engagement would be expected to be required for residents or other beneficiary groups.

This report has been primarily delivered through a desktop study with input provided by experts and some relevant stakeholders. Additional stakeholder engagement has been planned as part of this project to further test the implementation strategy outlined in this report, including the role and responsibilities of key delivery partners. This will be an important step in finalising and implementing the strategy in Seychelles.

Appendix C High-level Financing Assessment Criteria

Criteria	Range of values/possible options	Description and application to appropriate sources of capital	Implications for coral reef restoration
Investment size/capital requirement	Large ($100+ million) Medium ($25-$100 million) Small (<$25 million)	Commercial debt market (i.e. an institutional investor) would require a large capital size to invest. It may be possible that a private placement can be made for smaller capital requirements, however, typically this would involve an impact investor who would be more likely to provide concessionary debt. National governments or multilateral development banks would provide capital of any size, and may be able to bundle together projects of similar types (e.g. through a municipal bond, SDG bond or similar) to finance a broad range of activities. Philanthropic sources would be more likely for smaller capital requirements, or part of a larger requirement where it can be targeted to a specific outcome related to the investment mandate. Project with no upfront capital requirements (or once a project has been built and is operational) may be funded through ongoing levies, fees or other payments. Generally, however, some form of working capital is required which could be provided through a grant.	The capital size required for coral reef restoration varies. Indicatively, this project has identified that an upfront capital requirement for Seychelles would be 18.4 - $26.7 million. Consequently, it would be difficult to realise it purely through commercial debt finance.
Financial return	Unable to generate Able to generate, unable to distinguish/quantify Calculable and demonstrable	The ability of a project to generate some type of revenue stream is critical for any finance involving the private sector. If no return on investment can be shown, there is no prospect for levering the private sector and public finance (grants) or philanthropic funding are the only options. If the project can demonstrate a revenue stream for a specific activity, it would be preferable that this activity is separated and, possibly financed separately to the remainder of the project. This strategy allows private financing to be directed to those activities of the project that are able to meet its investment criteria, freeing public funding for other purposes. In such as case the entity responsible for this 'separate project' will absorb the risks associated with its activities, again freeing up public authorities from such obligations.	Revenue streams related to coral reef restoration need to be identified and, where possible, separated to the extent that they can be bundled and sold to private investors. For example, carbon credits or biodiversity credits. It is possible that other forms of credits could be identified, for example 'Reef Credits' are being developed to finance restoration activities for the Great Barrier Reef[10]. Coral reef restoration requires the use of a coral nursery. The coral nursery, particularly at a larger scale, could be financed

[10] For more information: https://greencollar.com.au/reef-credits/

Criteria	Range of values/possible options	Description and application to appropriate sources of capital	Implications for coral reef restoration
			separately to the remainder of the project as it could operate as a standalone business with a calculable and demonstratable revenue stream (selling corals)[11]. *Sources of revenue are critical to the success of the project and are summarised in the section that follow this table.*
Return on investment timescale	Long-term (20+ years) Medium-term (5-20 years) Short-term (<5 years)	Bonds and other fixed-term instruments from commercial or concessionary debt providers can be for a range of durations (months – years).	Coral reef restoration will provide revenue streams over a long time-period. In this project, we have assumed at least 15 years. This makes coral reef restoration attractive to the use of a debt product to finance, subject to other criteria.
Insurability	Uninsurable Partly insurable Insurable	Private financing and/or PPP requires some form of insurance. It may be possible that only part of the project is insurable, in which case private financiers would seek to contain their liability and a separation of risk to other, non-insurable parts of the project. The use of government or development capital ('risk capital') through a blended finance approach (i.e. first loss position, for example) and/or guarantees is designed to help leverage private financing by de-risking their potential liability in the case that the project does not perform to expectations.	Coral reef restoration may be considered a high-risk investment, in that there is a degree of uncertainty related to the rate of live coral growth and survival, which can be affected by weather and temperature. This risk is also relevant for ocean-based coral nurseries. Private financiers would seek to limit their exposure to this risk, including seeking alternative insurance products, such as the parametric insurance product used in Quintana Roo, Mexico.
Program attribution to achieving social, economic or	Difficult to demonstrate clear outcomes and their relationship to the program Possible to determine some outcomes and	Demonstrating a clear relationship between the activities of the program and the outcomes sought is particularly important for government, development bank, impact investors and philanthropic sources of capital. This is often because these sources of capital seek non-financial returns in addition to or instead of financial returns.	Coral reef restoration provides a range of demonstrable benefits. Clear attribution between the coral reef restoration and the specific outcomes sought by investors is important to attract these sources of capital.

11 Aither understands that a separate regional project will commence in August 2019 investigating the potential for coordinating coral reef restoration activities in Seychelles and Mauritius, which will include investigating this concept.

Criteria	Range of values/possible options	Description and application to appropriate sources of capital	Implications for coral reef restoration
environmental outcomes	their relationship to the program Certainty on outcomes and their relationship to the activities of the program		The specific outcomes achieved and the timeframe of achievement varies according to the restoration approach taken. For example, hybrid structures may deliver tangible coastal resilience benefits within months, however biodiversity benefits may take substantively longer (15-20 years) to be achieved. These factors will not necessarily constrain these sources of capital however investors with an aligned mandate will be important to identify.
Ownership and governance	Government (sole owner, operator) Public-private-partnership Private	The question of ownership is very important if public-private-partnerships are used. Setting out ownership (i.e. who owns what part of the asset and profit) and responsibilities (who is responsible to build, operate, maintain and monitor) in a series of detailed contracts are key for successful PPPs.	Clear ownership and governance arrangements would be required for coral reef restoration. This has been achieved in other coral reef restoration programs through the use of an environmental trust, as well as support from national Government. The environmental trust has ownership and governance responsibility over the coral reef restoration efforts. Regulation is enacted in accordance with local laws that sets the mandate and governance structure of the trust.

Appendix D Revenue Streams

Potential revenue streams for large-scale coral reef restoration have been identified through the business model review. These options are considered for the business case presented in Section 3. Revenue streams considered in the business case are outlined below:

- **Admission fees for protected area or high-value, high-use area**: These would include levies or fees to access protected areas, specifically where coral reef restoration may be undertaken. It would be possible for this revenue source to be collected and used for a specific site or, collected at scale and redistributed.
- **Environmental markets**: Environmental markets continue to be developed globally and include the identification and monetisation of carbon credits, biodiversity credits, etc… which can be sold directly to private investors or in secondary markets. In Seychelles, carbon credits could be generated by coral reef restoration due to the carbon sequestration of coral reefs[12], seagrass and mangroves, which coral reefs protect. Known as 'Blue Carbon', this is an emerging environmental market where further investigation is warranted.
- **Green taxes/levies**: Green taxes/levies are public mechanisms that are used to collect revenue. For example, this could include an existence levy on residents, a tax on tourists or a biodiversity offset used collect revenue from businesses whose activities may cause damage to a reef. In Seychelles, the CSR tax would be an example of a targeted green tax, which is imposed upon larger businesses (defined by revenue).
- **Voluntary contributions** (donations): This revenue stream includes small donations from tourists, residents or businesses. This would include donations made at a specific site or more generally (e.g. collection points at ports or airports). Alternatively, donations could be sourced through online mechanisms, such as through a crowd funding campaign.
- **New business ventures, including export markets**: New business ventures could be established and profits used to fund the coral reef restoration. New business ventures may include tour operators taking people to visit the coral reef or fees for tourists and educational programs at coral nurseries. For coral reef restoration, the coral nursery itself could become a standalone business venture to supply both local coral reef restoration requirements, as well as export of corals[13]. Given the substantive skills and experience that would be developed of the program was implemented it may also be possible to export these, including through new training courses and qualifications.

The appropriateness and implementation of each potential revenue stream is dependent upon the scale of the coral reef restoration. At a specific site (e.g. La Passe), local beneficiaries are the most likely to receive a direct benefit and consequently, a revenue stream which is directly linked to that benefit could be prioritised. For example, if coral reef restoration was to occur at scale sufficient to reduce coastal erosion and flooding on La Passe, local tourism businesses and the local community may be willing to pay for this benefit. Admission fees may also be appropriate for tourists or residents to access the restored site. At scale however (e.g. green tax),

[12] The carbon sequestration benefits of coral reefs themselves is not clearly agreed to in scientific literature. However, the carbon benefits generated by coral reef restoration would include the carbon benefits attributed to those ecosystems it protects, such as mangroves and seagrass. Consequently, mangroves and seagrasses are the focus of this potential revenue stream for this project.
[13] The species of coral suitable for restoration in Seychelles are not necessarily suitable for the most active export market, which focuses on ornamental corals. However, coral export could include species suitable for coral restoration, such as in Mauritius. The cost to transport corals may also be a limiting factor to a coral export business.

a centralised collection and distribution system is beneficial. This will allow the selection of the most appropriate coral reef restoration sites based on a wider range of criteria (for example, ecological importance or the areas which have the highest coastal erosion or flood risk which can be resolved through coral reef restoration).

The selection of a revenue stream is also dependent upon the willingness for government to introduce new fees, taxes or levies. There would need to be a significant effort to build support from the relevant party or those that may be affected. For example, the tourism industry may be resistant to a new fee on tourists if it is possible that it will reduce the number of tourists. A willingness to pay study can be used to help inform an understanding of which of these options may be appropriate and not put local business revenues at risk.

Appendix E Case Study

La Passe (aka La Passe CZMU 11)

Identified Problem(s): Coastal erosion is the main problem in this zone (Figure 6 13). The reef is located 250-300 m from the shoreline and loss of reef could lead to local flooding and further erosion. The area is predicted to suffer a moderate to high reduction in wave run-up (Deltares). The area is classified as having one of the highest vulnerabilities to flooding due to extreme weather (Alvarez Cruz et al. 2011).

Objectives of Coral Reef Restoration: Provide substantial protection from waves, helping to reduce erosion. Benefits to tourism – diving and snorkelling.

Limitations to Coral Reef Restoration: The reef flat in this region is extremely shallow (0.5-1 m) and much of it near the shore is exposed during the spring low tides. RRA surveys found little live hard coral cover, suggesting little coral recruitment is likely to be available. Bedrock at this site is covered in turf algae and zoanthid mats, as well as sea grass, resulting in little substrate available for whatever coral recruitment there might be. Few herbivorous fish were recorded possibly due to fishing activities in the region, although none were witnessed during the site visit. There is likely to be human impact on the reef flats in the form of fishing (boats) and reef trampling (for octopus). There is also nutrient in-put into the system via run-off from high-residential area, likely exacerbating the growth of macroalgae on the reef flats. North-west trade winds cause rough sea conditions between December - March each year.

Opportunities for Coral Reef Restoration: No obvious opportunities for coral reef restoration through live corals on the reef flat.

Potential Options: A better understanding of the benthic environment on the reef slope is needed. If coral cover is extremely low on the reef slope (as expected) and the reef crest is likely to collapse, possible near-shore interventions could include submerged break-waters or other submerged barriers, preferably of the hybrid type as described previously. Coral-restoration on the reef flat is unlikely to work because of shallow nature of the reef flat, but could possibly work along the reef slope. If coral transplantation is possible on the slope nurseries would need to be situated in an alternative in-situ location (slightly deeper and less exposed) or the use of ex-situ tank nurseries would be needed.

Overview of Area Assessed for the Economic Evaluation

The economic analysis undertaken in Task 2 examined the assets along the populated areas of the western coastline of La Digue, including La Passe. This area comprises the primary area of economic activity on the island. The area includes a range of environmental, social and economic assets, including:

- Hotels, private residences, cafes and restaurants;
- Hospitals, marina and roads;
- Extensive sandy beaches and lagoons;
- Large areas of seagrass and areas of coastal mangroves to the south of La Passe; and
- Limited agricultural land.

Coral reef on the western coastline provides protection for these assets as well as being an attraction for tourists and locals.

Summary of Task 1 Assessment on La Passe: Outcomes and Costs

The reef condition is considered to be poor, with very low live coral cover compared to other species and large areas of rubble and bare rock (BMT 2019). There was little evidence of any recently dead coral at the two sites, suggesting that the lack of coral is likely to be due to historic bleaching events rather than more recent events. It therefore appears there has been a lack of response following the significant bleaching events which have occurred in the past (BMT 2019).

Primary and Secondary Outcomes

A high-level summary of the baseline condition of the primary and secondary outcomes using the cost benefit analysis framework is shown in Table E-1. The focus is understanding the likely baseline, as identified through the current work program (BMT 2019), from which the potential impact of any intervention can be assessed.

Table E-1 Primary and secondary outcomes

	Description
Primary outcomes	
Increased coral species (diversity and abundance)	Low level of existing coral species, with the area predominantly rubble and bare rock. It is technically feasible that live coral is used as a restoration option in La Passe however this is expected to be limited to the slope of the reef, not the reef flat. Whether this is an appropriate technique will depend upon a range of criteria, including whether there are likely to be significant tourism (or other) benefits for reef restoration using live coral.
Increase in other ecosystem functions	Low levels of fish biomass identified on the reef, whilst sea urchins abundant. High potential for coral reef restoration to attract additional fish biomass, if an appropriate restoration method is applied.
Reduced beach erosion	High risk of beach erosion identified in the La Passe area, with evidence of existing coastal erosion being substantive. The loss of the reef is likely to increase the risk of beach erosion.
Reduced flooding	High risk of flooding identified in the La Passe area due to extreme weather. The loss of the reef is likely to increase the risk of flood vulnerability.
Other environmental protection (e.g. seagrass and mangroves)	The reef currently provides protection to an extensive area of seagrass and limited areas of mangroves and other stabilising vegetation on the shoreline. The loss of the reef is likely to result in the loss of these environmental assets.
Secondary outcomes	
Increased recreational value and use	The area is used extensively for beach recreation (being a key attraction to the area for tourists), kayaking and other activities. However, there is limited dive and snorkelling activities with the diving industry in decline.
Increased ecosystem services (e.g. increased carbon sequestration)	Seagrass protected by the reef provides carbon sequestration services. The reef does not provide high-levels of provisioning services for fish and other marine life, evidenced by low levels of biomass.

	Description
Reduced damage	The reef helps to reduce damage to private homes, hotels, businesses (cafes, restaurants, limited agriculture), economic infrastructure (roads, marina) and social infrastructure (e.g. Logan Hospital) from extreme flood events, however La Passe remains vulnerable to flood during extreme weather.
Increased non-use value	No clear evidence identified. A survey undertaken by Goizueta (2018) with local businesses identified they were aware of the importance of the reef and its poor state.

Summary of Benefits

A number of potential benefits can be identified for La Passe through the implementation of coral reef restoration. A brief description of the likely benefits is provided in Table E-2, based on the outcomes identified through Task 1 and using values identified through desktop research. These benefits have been identified at a high level at this stage of the assessment. A more detailed CBA would require further clarity on the extent to which benefits can be attributed to individual project outcomes.

Table E-2 Benefits of coral reef restoration

	Description
Benefits	
Tourism benefits	Tourism benefits are likely to accrue in La Passe as a result of coral reef restoration. The key drivers of tourism benefits include: Increased visitation and beach use value for tourists due to reduced erosion, and reduced need for protective infrastructure in the future. Research by Phillips (2011) showed that significant value is placed on beaches without manmade protection infrastructure such as groynes or sea walls, which is predominantly the case in La Passe. Potential for increased snorkelling, diving and fishing recreation from tourists due to increases in live coral and other marine biomass, which is currently limited in La Passe but has been demonstrated to have a high value in other studies. Goizueta (2018) indicates that tourists currently chose to visit La Digue for reasons other than these recreational activities, such as beaches, bike tours or 'creole vibe', improved reef health may increase the numbers visiting specifically to undertake recreational activities associated with the reef. Diving and snorkelling may also see increases due to the actual activity of coral reef restoration as has been demonstrated in other areas in the Seychelles. There are also potential benefits delivered by reduced damage from flooding which would otherwise negatively affect the tourism industry in La Passe. For example, the CZMU (2018) identified 8 hotels in La Passe that would be affected by 1 in 25 year floods, which would affect tourism in the area. The island of La Digue is visited by significant numbers of tourists each year, therefore these benefits are likely to be highly important to the overall value of the coral reef restoration projects. Previous research by Cesar et al. (2004) suggested that the annual recreational value of snorkelers in La Digue in 2005 was approximately $7.5 million ($US 2005) based on a WTP survey. Research in St Vincent and the Grenadines (Christie et al, 2015) showed that tourists were willing to pay $88.48 per household per year to improve

	Description
	six ecosystem services including; fishing, coastal protection, human health, ecosystem resilience, beach recreation, and diving/snorkelling.
Community benefits	Community benefits are also likely to occur in La Passe as a result of the coral reef restoration activities. The key drivers for community benefits include: Increased visitation and use value of the beach for local residents as described above. Increased visitation and recreation value from snorkelling, diving and fishing for local residents as described above. Reduced flood damage costs to private property in the area, or reduced expenditure on private flood protection. Increased non-use value of the coral reef due to existence, bequest and cultural values. These benefits on a per person basis may be relatively high, for example the study in St Vincent and the Grenadines discussed above found that locals had a WTP of $54.41 for improvement in six ecosystem service benefits. However, the local population is relatively small with 2,800 people in the whole of La Digue, concentrated around La Passe. Therefore, these benefits may be of lower total value than the tourism benefits identified above. This is shown in Cesar et al. (2004) which suggests the annual recreational value of snorkelling to local residents in La Digue in 2005 was approximately $1 million, compared to $7.5million for tourists ($US 2005).
Local business benefits (non-tourism related)	Local business benefits in this area may include: Artisanal fishing is of paramount importance to the Seychellois. It is largely limited to the Mahé Plateau that comprises the islands of Mahé, Praslin, and La Digue. The plateau is fished by 140 whaler and schooner-type vessels and at least 400 outboard motor vessels, as well as sport and recreational fishing boats. The total annual landed catch amounts to more than 4,000 tons, valued at around $US12.5 million and supplies most of the domestic market (World Bank, 2017). The volume and value of fish catch may be increased due to reef restoration creating value for local businesses both directly and indirectly involved in artisanal fishing. The artisanal demersal fishery is of paramount importance to the Seychellois. Depending upon the coral reef restoration type and business model, it may be possible that a local business is established to undertake coral reef propagation and gardening or other activities associated with reef restoration. Currently, these types of business activities occur on other islands such as Mahé. Research by Cesar et al (2004) suggests that the increase in the annual value of fisheries in La Digue due to increased fish catch would be approximately $36,000 ($US 2005).
Other ecosystem service benefits (e.g. value of carbon sequestered)	Other ecosystem services identified around La Passe include carbon sequestration within seagrass beds and coastal stabilisation due to mangroves and other fringing vegetation. Depending on the extent to which reef restoration protects these ecosystems there will be benefits due to an increase or prevented decline in these services.
Avoided infrastructure costs	There are likely to be improved beach protection outcomes due to coral reef restoration. In La Passe this would reduce the cost of implementing new beach or flood protection measures such as sea walls or groynes, or replacement of damaged infrastructure (e.g. roads and hospitals) due to

	Description
	flooding. The CZMU (2018) shows that approximately 10km of roads as well as the hospital and community centre are within the area affected by 1-in-25-year flood events.

Results of Multi-criteria Analysis

Given the limited data available specific to La Passe, a detailed CBA was unable to be undertaken. However, a desktop multi-criteria analysis (MCA) was undertaken for La Passe to support the economic evaluation. This approach can be useful to inform which benefits may be of greatest importance for each site, as well as providing an understanding of the trade-offs between different options. Three possible options for coral reef restoration are used to inform the MCA, which can be used to highlight the different types of benefits possible. The three options are:

- Option 1: Artificial reef sited to reduce wave runup – involves developing and deploying new artificial structures to provide protection from flooding and erosion.
- Option 2: Artificial reef with coral gardening sited to support coral growth – involves developing and deploying new artificial structures with additional provision of live coral on new substrate.
- Option 3: Coral Gardening, Transplantation and Microfragmentation – involves the provision of live coral on existing substrate.

All three options have been assessed relative to a “no action” scenario, whereby no coral reef restoration activities are undertaken meaning that the results show the ‘delta’ of each of the three options assessed (i.e. a “no action” option would measure as a zero against each of the benefit types in Table A3). The results of the desktop MCA are presented in Table E-3.

Table E-3 MCA results

Benefit type	Weighting	Option 1	Option 2	Option 3
Benefits				
Tourism benefits including benefits for businesses	40%	2	4	3
Community benefits including coastal resilience	20%	2	4	3
Local business benefits (non-tourism related)	5%	1	4	4
Other ecosystem service benefits	5%	4	3	2
Avoided infrastructure costs	30%	4	3	2
FINAL SCORE (weighted total)		**2.65**	**3.65**	**2.7**
Costs				
Upfront expenditure		High	Medium	Medium
Ongoing maintenance		Low	High	High
Opportunity costs		Low	Medium	High
Risks				

Benefit type	Weighting	Option 1	Option 2	Option 3
		Low	Medium	High

The value of the benefits assessed through the MCA are related to both the description of the benefits provided in Table E-3, and to the specific reef restoration options described above. The rationale for the values assigned for each option are:

- Tourism benefits – tourism benefits are related to the presence of coral and other marine species but also to beach condition and flooding. Option 1 provides limited expected improvement in coral condition or marine diversity but reduces the risk of beach erosion and flooding. Option 2 also reduces the risk of beach erosion and flooding, although to a lesser extent, with greater potential for improvements in coral and marine biomass. Option 3 provides a much greater potential for live coral and increased marine biomass and diversity, however it is likely to take much longer to provide protection against beach erosion or flooding.
- Community benefits – these are expected to be affected in the same way as described for tourism benefits.
- Local business benefits (non-tourism related) – these benefits are related to fishing and the presence of industries related to reef restoration. These benefits are likely to be most significant under Options 2 and 3.
- Other ecosystem service benefits – these benefits are directly related to the protection provided by the reef structures to other ecosystems such as seagrass and mangroves. As discussed in relation to beach erosion, Option 1 is most likely to generate these benefits, particularly in the short-term as Option 3 is constrained to the reef shoulder not the reef flat.
- Avoided infrastructure costs – again these benefits are related to beach erosion and flooding, with Option 1 most likely to deliver these benefits.
- Costs – the relative costs of each type of reef restoration are based on information from relevant stakeholders.
- Risks – Option 1 is expected to have lower risks associated with it as the outcomes are based on reduced beach erosion and flooding using an engineered artificial structure. Option 3 faces the highest risks as the outcomes are dependent on successful coral propagation which will take longer to generate benefits. There are also risks associated with the management practices required to successfully undertake live coral provision, including banning access to the reef for recreational activities, which would significantly decrease the benefits of this option.

Conclusions

The desktop economic analysis of La Passe has highlighted that coral reef restoration will provide several important economic benefits. The benefits which are likely to deliver the highest value in La Passe are:

- Tourism benefits: tourism benefits are likely to be high. Tourism benefits will be provided if the coral reef restoration protects the beaches in La Passe, which are a key asset that currently draws tourists to the island. New tourism will also be established if the coral reef restoration technique involves an increase in live coral and increases fish and other marine biomass.
- Avoided infrastructure costs: coral reef restoration can also offset future infrastructure requirements to protect the coast from erosion.

The rapid MCA assessment demonstrates that Option 2 is the most likely to deliver the highest benefits. This is due to the potentially high values placed on the presence of live coral and marine biodiversity by both tourists and local residents, as demonstrated in other areas. However, this option presents higher ongoing costs and risks than Option 1, which still delivers benefits in terms of reduced beach erosion, flood protection and protection of other ecosystems.

The next step in this study is to conduct stakeholder interviews to gain a better understanding of what is feasible in the local context, and which benefits are more highly valued by the residents of La Digue, the Government of the Seychelles, and the wider population. If sufficient data is available a rapid CBA will also be undertaken. At this stage detailed cost estimates for feasible restoration options will be developed and compared against the benefits of the options, including the avoided costs currently incurred to undertake restorative work currently. This approach will be undertaken as part of Task 3 if this site is selected as the preferred option for a detailed case study.

The three reef restoration options are potentially suitable for a number of different financing mechanisms. At a high level, Options 2 and 3 may be suitable for a tourism tax approach (e.g. tourism-based user fee or voluntary surcharge program), given the majority of the benefits are delivered through recreational use of the coral reef itself whether through diving, snorkelling or fishing. Option 1 may be more suitable for a financing mechanism that generates cash flow due to the benefits of reduced beach erosion and flood protection which will accrue to hotels and tourist operators in the area (e.g. insurance or income from commercial activities). It will be important to fully explore these distributional impacts more thoroughly during the next stage of work.

Appendix F Detailed Information on Priority Sites

Priority Sites on Mahe

Sites	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Baie Ternay	Beau Vallon	North East Point	Summary for Mahe
Primary objective of reef restoration	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Biodiversity conservation	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)
Other expected outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Potential tourism, some wave energy reduction, reduced erosion	Some potential tourism/use-benefits/ biodiversity outcomes	Some potential tourism/use-benefits/ biodiversity outcomes	Some potential tourism/use-benefits/ biodiversity outcomes
Identified problems including run-up, flooding, erosion	Reefs are degrading after multiple bleaching events and wave run-up reduction is low in the north rising to severe in the south	Reduction in wave run-up is moderate to severe in the northern sector, local reefs are likely degrading after multiple bleaching events.	Vulnerability to flooding due to severe weather is low to medium (Alvarez Cruz et al. 2011), low to moderate reduction in wave run-up predicted in this area	Erosion, wave overtopping, wave run-up and washed-up coral debris have been identified as problems in this region	Local erosion and flooding during storm events, as well as wave overtopping during high tides, predicted to have moderate to severe reduction in	Erosion and flooding during spring high tides and during storms/heavy rainfall (Alvarez Cruz et al. 2011). Wave overtopping onto roads also occurs and the	Beach erosion could be a problem with degradation of carbonate reef system in centre of the bay while reduction in wave run-up is moderate	The wave run-up predictive model suggest this area has one of the greatest run-up reductions predicted in the inner islands due to the absence of any reef	Long-term erosion, wave run-up and wave overtopping onto low-lying coastal roads	Varying problems identified

Sites	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Baie Ternay	Beau Vallon	North East Point	Summary for Mahe
					wave run-up	area is predicted to have a moderate reduction of wave run-up		structures in the centre of the bay.		
Extent of restoration	200 m x 5 m x 2 (2000 m^2)	100 m x 5 m x 4 (2000 m^2)	200 m x 5 m x 2 (2000m^2)	200 m x 5 m x 2 (2000 m^2)	200 m x 5 m x 3 (3000 m^2)	150 m x 5 m x 2 (1500 m^2)	100 m x 5 m x 2 (1000 m^2)	200 m x 5 m x 2 (2000 m^2)	100 m x 5 m x 4 (2000 m^2)	23 sites
Total m^2	2000	2000	2000	2000	3000	1500	1000	2000	2000	17500
Suggested type of restoration	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Hybrid reef modules with coral transplantation	Direct coral transplantation; possible some rubble stabilisation	Hybrid reef modules with coral transplantation	Substantial hybrid reef modules with coral transplantation	Substantial hybrid reef modules with coral transplantation, some direct transplantation
Coral fragments required	6,000-21,000	6,000-21,000	6,000-21,000	6,000-21,000	9,000-31,500	4,500-15,750	5,000	6,000-21,000	6,000-21,000	54,500-178,250
Type of nursery	Land-based	Land-based	Land-based	Land-based	Land-based	Land-based	Ocean-based	Land-based	Land-based	Majority land-based

Sites	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Baie Ternay	Beau Vallon	North East Point	Summary for Mahe
Expected cost of restoration (upfront)	$1,433,600-$2,154,800	$1,433,600-$2,154,800	$1,433,600-$2,154,800	$1,433,600-$2,154,800	$2,142,050-$2,921,900	$1,079,375-$1,620,313	$248,250	$1,433,600-$2,154,800	$1,433,600-$2,154,800	$12,071,275-$17,719,263
Ongoing monitoring costs ($/m^2)	$96,000	$96,000	$96,000	$96,000	$144,000	$72,000	$48,000	$96,000	$96,000	$840,000
Site identified for measures in CMP?	Yes (CZMU-02)	Yes (CZMU-03)	Yes (CZMU-04)	Yes (CZMU-05)	Yes (CZMU-06)	Yes (CZMU-08)	No	Yes (CZMU-07)	Yes (CZMU-01)	Yes
Reef restoration identified in CMP?	No	Yes	No	Yes	No	No	No	No	Yes	Mixed
Other restoration identified in CMP (costs)	Breakwaters, rock armouring	Breakwater	Rock Armouring	Beach and dune management and restoration	Backshore dune vegetation management & restoration	Retaining wall, backshore dune vegetation management and restoration	N/A	Retaining wall, backshore dune vegetation management and restoration	Low Crested Breakwater or detached breakwaters	Various

Sites	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Baie Ternay	Beau Vallon	North East Point	Summary for Mahe
Costs of other restoration	$837,000	$320,000	$54,000	$1,425,000	$600,000	$3,271,000	N/A	$1,265,000	$640,000	$8,412,000
Run up reduction (Pearson et al. 2018)	High potential runup reduction due to wide reef	the wide reefs at this location have a high potential for wave runup reduction	High wave runup reduction potential	Potential runup reduction highly variable as a result of the complexity of the coastline.	High runup reduction potential, although varied across the bay, with the area with no reef having lower potential.	Runup reduction potential at the southern end of the bay, but low runup reduction potential at the northern end of the bay.	Uncertainty about the depth of the reef at this location. Runup modelling shows variable results, including runoff reduction at the wider part of the reef (central).	Wide reefs at this location have a high potential for wave runup reduction, although there is a very mild fore reef slope.	Potential runup reduction highly variable as a result of the complexity of the coastline.	
Tourism potential	Swimming/ snorkelling	Fishing/ swimming/ snorkelling	Fishing/ swimming/ snorkelling/ diving	Swimming/ snorkelling	Swimming/ snorkelling/ fishing	Swimming/ snorkelling	Swimming and snorkelling, fishing	Fishing/ swimming/ snorkelling/ diving		Fishing/ swimming/ snorkelling/ diving
	Lower visitation	higher local visitation	Beach – highly rated , high visitation	Beach – highly rated, high visitation	Some visitation	Low visitation	Low visitation	High visitation	Low visitation	High visitation

Sites	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Baie Ternay	Beau Vallon	North East Point	Summary for Mahe
Blue carbon potential	Low	Low	High - extensive (but declining) seagrass beds, mangroves	Medium - Seagrass beds	Medium - seagrass beds.	High - Seagrass beds, mangroves,	High - seagrass beds and mangroves	Low	Low	Mixed
Mangrove extent (ha)	-	-	3	0	0	9		-	-	12
Seagrass extent (ha)	-	-	10	9	9	4		-	-	32
Total carbon storage potential (tCO2e/year)	-	-	10552	5463	5463	15722		-	-	37200
Total carbon storage value ($/year)	-	-	$105,520	$54,630	$54,630	$157,223		-	-	$372,003
Climate change	Effects of climate change will be similar across all locations. Sea-level rise, warmer ocean temperatures, increasing acidity. However, sites where effects of past bleaching were not as strong may have some additional resilience									

Sites	Anse aux Pins	Au Cap	Anse Royale	Baie Lazare	Anse La Mouche	Anse Boileau	Baie Ternay	Beau Vallon	North East Point	Summary for Mahe
Human activities on reef	Substantial impacts from tramping on reef octopus hunting and from fishing activity		Tourist impacts, boat anchoring, overfishing	Reef excavated to form a channel	Anchorage for local boats and fishing vessels		Snorkelling, diving and boat anchoring have affected reef			
Nutrient run-off or pollution	Nutrient runoff from surrounding area	Nutrient runoff from surrounding area	Nutrient runoff from surrounding area	Nutrient runoff from surrounding area	Nutrient runoff from surrounding area	Nutrient runoff from surrounding area		Nutrient runoff from surrounding area	Nutrient runoff from surrounding area	
Risk of not achieving outcomes	High risk if substantial additional manageme nt is not put into place and enforced, and macroalgae are not managed. Need for additional engineered structures	High risk if substantial additional manageme nt is not put into place and enforced, and macroalgae are not managed. Needs additional engineered structures	High risk if substantial additional manageme nt is not put into place and enforced, and macroalgae are not managed.	High risk if substantial additional manageme nt is not put into place and enforced, and macroalgae are not managed.	High risk if substantial additional manageme nt is not put into place and enforced, and macroalgae are not managed.	Nutrient manageme nt required	High risk if substantial additional manageme nt is not put into place and enforced	Nutrient manageme nt required	Nutrient manageme nt required. Additional engineered structures required as well.	

Priority Sites at La Digue and Praslin

Sites	La Passe	Anse Consolation	Grand Anse	Anse Boudin	Summary for La Digue/Praslin
Primary objective of reef restoration	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)	Wave energy reduction (reducing erosion and flooding)
Other expected outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes	Some potential tourism/amenity benefits/ biodiversity outcomes
Identified problems including run-up, flooding, erosion	loss of reef could lead to local flooding and further erosion. The area is predicted to suffer a moderate to high reduction in wave run-up	The area is predicted to suffer a moderate reduction in wave run-up	The area is predicted to suffer a moderate to severe (in the centre) reduction in wave run-up	The area is classified as one of the highest vulnerability to flooding due to extreme weather	Varying problems identified
Extent of restoration	100 m x 5 m x 2 (1000 m^2)	50 m x 5 m x 2 (500 m^2)	100 m x 5 m x 6 (3000 m^2)	50 m x 5 m x 4 (1000 m^2)	14 sites
Total m^2	1000	500	3000	1000	5500
Suggested type of restoration	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation	Some direct transplantation & hybrid reef modules with coral transplantation
Coral fragments required	3,000-10,500	1,500-5250	9,000-31,500	3,000-10,500	16,500-57,750
Type of nursery	Land-based	Land-based	Land-based	Land-based	Land-based
Expected cost of restoration (upfront)	$725,150-$1,085,775	$370,925-$551,238	$2,142,050-$2,921,900	$725,150-$1,085,775	$3,963,275-$5,644,688

Sites	La Passe	Anse Consolation	Grand Anse	Anse Boudin	Summary for La Digue/Praslin
Ongoing monitoring costs ($/m^2)	$48,000	$48,000	$144,000	$48,000	$288,000
Site identified for measures in CMP?	Yes (CZMU-10/11)	Yes (CZMU-14)	Yes (CZMU-15)	Yes (CZMU-17)	Yes
Reef restoration identified in CMP?	Yes	No	No	No	Limited
Other restoration identified in CMP (costs)	Groynes, rock armouring with sand nourishment, backshore dune vegetation management and restoration	Rock Armouring (include backfilling with sand)	Backshore dune vegetation management & restoration	Backshore dune vegetation management & restoration	Various
Costs of other restoration	$944,705	$54,000	$600,000	$300,000	$1,898,705
Run up reduction (Pearson et al. 2018)	Highest potential runup reduction on La Digue.				
Tourism potential	Swimming /snorkelling	No water activities	Swimming/ snorkelling	Fishing/swimming/ snorkelling	Fishing/swimming/ snorkelling
	Moderate visitation	Low visitation	Moderate visitation	Low visitiation from tourists, local fishing spot	Moderate visitation
Blue carbon potential	Medium - Seagrass	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.

Sites	La Passe	Anse Consolation	Grand Anse	Anse Boudin	Summary for La Digue/Praslin
Mangrove extent (ha)	0				
Seagrass extent (ha)	4				
Total carbon storage potential (tCO2e/year)	2428				
Total carbon storage value ($/year)	$24,280				
Climate change	Effects of climate change will be similar across all locations. Sea-level rise, warmer ocean temperatures, increasing acidity. However, sites where effects of past bleaching were not as strong may have some additional resilience.				
Human activities on reef	Substantial impact from trampling and community usage	low impact from trampling and community usage	Substantial impact from trampling and community usage	Substantial impact from trampling and community usage	
Nutrient run-off or pollution	Nutrient runoff from surrounding area	Low levels of nutrients	Some runoff	Little runoff	
Risk of not achieving outcomes	High risk if substantial additional management is not put into place and enforced, and macroalgae are not managed.	Lower risk	Low risk but further investigation required	Low risk	

Priority Sites at Grand Seour and Petite Seour

Sites	Petite Soeur	Grande Soeur	Summary for both islands
Primary objective of reef restoration	Biodiversity outcomes	Biodiversity outcomes	Biodiversity outcomes
Other expected outcomes	Tourism, fishing, erosion reduction	Tourism, fishing, erosion reduction	Tourism, fishing, erosion reduction
Identified problems including run-up, flooding, erosion	No information available	No information available	No information available
Extent of restoration	100 m x 5 m x 2 (1000 m^2)	100 m x 5 m x 2 (1000 m^2)	4 sites
Total m^2	1000	1000	2000
Suggested type of restoration	Direct coral transplantation; possible some rubble stabilisation	Direct coral transplantation; possible some rubble stabilisation	Direct coral transplantation; possible some rubble stabilisation
Coral fragments required	5,000	5,000	10,000
Type of nursery	Ocean-based	Ocean-based	Ocean-based
Expected cost of restoration (upfront)	$248,250	$248,250	$496,500
Ongoing monitoring costs ($/m^2)	$48,000	$48,000	$96,000
Site identified for measures in CMP?	No	No	No
Reef restoration identified in CMP?	No	No	No
Other restoration identified in CMP (costs)	N/A	N/A	N/A
Costs of other restoration	N/A	N/A	N/A
Run up reduction (Pearson et al. 2018)	No information	No information	No information
Tourism potential	Very limited tourist visitation	Very limited tourist visitation	Very limited tourist visitation

Sites	Petite Soeur	Grande Soeur	Summary for both islands
Blue carbon potential	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.	Little information available about the reef and surrounding habitat.
Climate change	Effects of climate change will be similar across all locations. Sea-level rise, warmer ocean temperatures, increasing acidity. However, sites where effects of past bleaching were not as strong may have some additional resilience.		
Human activities on reef	Minor impact from human use		
Nutrient run-off or pollution	N/A		
Risk of not achieving outcomes	Low risk	Low risk	Low risk

Appendix G Assumptions for Economic Analysis

Assumption	Value	Unit	Notes
Coral density			
Live coral transplantation and gardening	5	colonies/m^2 of seabed	Assuming no structure
Artificial reef	0	colonies/m^2 of seabed	Coral friendly concrete modules, two lower and one upper module
Artificial reef with coral (concrete)	3	colonies/m^2 of seabed	Coral friendly concrete modules, two lower and one upper module
Artificial reef with coral (steel)	10.5	colonies/m^2 of seabed	Welded steel frame tunnel of 2m width and 1m height
Coral required			
Live coral transplantation and gardening	5000	colonies	Calculated based on extent and coral density
Artificial reef	0	colonies	Calculated based on extent and coral density
Artificial reef with coral (concrete)	3000	colonies	Calculated based on extent and coral density
Artificial reef with coral (steel)	10500	colonies	Calculated based on extent and coral density
Nursery costs - land based			
First 1000 colonies	53.00	$/colony	Based on 1000 fragment ex-situ nursery
Subsequent colonies	36.30	$/colony	Based on 1000 fragment ex-situ nursery
Colony growth rate	1333	colonies/year	Based on 1000 fragment ex-situ nursery with nine month growth cycle
Nursery costs - ocean based			
For 5000 colonies	16	$/colony	Based on 5000 fragment in-situ nursery including population and maintenance
Growth rate	5000	colonies/year	

Assumption	Value	Unit	Notes
Transplantation costs	2.45	\$/colony	Based on transplantation costs of \$9/m^2 with 5 colonies per m^2 for diver and boat
Structural costs			
Live coral transplantation and gardening	0	\$/m^2	Assuming no structure
Artificial reef	84	\$/m^2	Coral friendly concrete modules, two lower and one upper module
Artificial reef with coral (concrete)	91	\$/m^2	Coral friendly concrete modules, two lower and one upper module (\$146/m^2 minus transplantation costs of \$2/colony and coral costs of \$16/colony with 3 colonies/m^2)
Artificial reef with coral (steel)	156	\$/m^2	Welded steel frame tunnel of 2mx1m (\$350/m^2 minus transplantation costs of \$2/colony and coral costs of \$16/colony with 10.5 colonies/m^2)
Algae removal costs			
Live coral transplantation and gardening	12	\$/m^2/week	Maintenance of transplanted sites (algal removal and cleaning once per week for first 3 months)
Artificial reef	0	\$/m^2/week	Non assumed
Artificial reef with coral (concrete)	38.4	\$/m^2/week	Maintenance of transplanted sites (algal removal and cleaning once per week for first 3 months) @ 12\$ per m^2 of tunnel surface area with 3.2 m^2 per 1m^2 of sea bed
Artificial reef with coral (steel)	38.4	\$/m^2/week	Maintenance of transplanted sites (algal removal and cleaning once per week for first 3 months) @ 12\$ per m^2 of tunnel surface area with 3.2 m^2 per 1m^2 of sea bed
Time spent on algae removal	13	weeks	Once a week for 3 months
Ongoing monitoring costs - monthly			
Live coral transplantation and gardening	4	\$/m^2	Monthly monitoring of growth , & percentage loss at transplanted sites using tagged corals & band transects, ongoing for 20 years
Artificial reef	0	\$/m^2	Non assumed
Artificial reef with coral (concrete)	4	\$/m^2	Monthly monitoring of growth , & percentage loss at transplanted sites using tagged corals & band transects, ongoing for 20 years
Artificial reef with coral (steel)	4	\$/m^2	Monthly monitoring of growth , & percentage loss at transplanted sites using tagged corals & band transects, ongoing for 20 years

Assumption	Value	Unit	Notes
Blue carbon benefits			
Mangroves - carbon sequestration (tCO2e/ha)	1494	tCO2e/ha	https://www.thebluecarboninitiative.org/about-blue-carbon
Seagrass - carbon sequestration (tCO2e/ha)	607	tCO2e/ha	https://www.thebluecarboninitiative.org/about-blue-carbon
Total carbon storage value ($/year)	10	USD/tCO2e	https://www.worldbank.org/en/results/2017/12/01/carbon-pricing

Summary of costs for each option

Cost ($/m^2)	Coral costs (land based first 1000 fragments)	Coral costs (land based after first 1000 fragments)	Coral costs (ocean based)	Transplantation costs (one off)	Structural costs (one off)	Algae removal costs (one off)	Ongoing monitoring costs per year
Live coral transplantation and gardening	265	181.5	80	12	0	156	48
Artificial reef	0	0	0	0	84	0	0
Artificial reef with coral (concrete)	159	108.9	48	7	91	499	48
Artificial reef with coral (steel)	556.5	381.15	168	26	156	499	48

Appendix H Restoration Literature Snapshot

Author/Company	Type	Location	Rationale	Methodology	Cost
(Suzuki, et al., 2011)	Artificial Reef	Urasoko Bay, Ishigaki Island, Japan.	Considers role of artificial plates in artificial restoration of coral communities.	Field experiments to examine whether differences in design of settlement plates (grid size/plate structure) influence initial survival rates of coral juveniles.	
(Tortolero, Cupul-Magana, & Rodriguez-Tronsco, 2014)	Artificial Reef + Transplantation	Bahia de Banderas, Nayarit, Mexico	Test re-attachment concept as an accelerator process to natural recovery based on asexual reproduction.	Collected 189 coral fragments and re-attached on artificial and natural substrates. Coral growth measurement, survivorship, mortality rates and sea water temperature recorded.	
(Al-Horani & Khalaf, 2013)	Artificial Reef	Gulf of Aqaba, Jordan	Deployment of artificial reef to test efficiency of restoring damaged reef/enhancing habitat. Study of the colonization of hard corals on artificial reef 3.5 years after deployment. Focus on structure/design/composition of AR units.	Construction/deployment of concrete units (1.5 x 1.5 x 1.5 block) deployed in three locations with three different set-ups. Water quality samples and visual census of coral recruitment undertaken at 3.5-year mark after deployment.	• Labour/material intensive. • Detailed planning
(Ng, T.C, & C, 2017)	Artificial Reef	Southern Offshore Island, Singapore	Assess the development of biological communities on REUs and evaluate long term effectiveness of AR as coral restoration tool in sediment affected environment.	Fibreglass REUs deployed in early 2000, surveyed in 2014. Early monitoring ceased in 2004. REUs surveyed using modified line intercepts transects.	• Fibreglass REUs – lightweight, easy to transport, readily deployable (no barge). • Fibreglass – short lifespan (20 years) – needs regular assessment.

Author/Company	Type	Location	Rationale	Methodology	Cost
					• Efficacy of REU is location specific, requires long term monitoring. • Upkeep of chains/anchors
(Sherman, Gilliam, & Spieler, 2002)	Artificial Reef	Florida, USA	Compare fish assemblages among three artificial reef design types with a focus on recruitment of fish with a floating line attachment and void space/complexity of design.	AR monitored 18 times in 2 years. Count and record census data of each plate over time.	
(Pennesi & Danovaro, 2017)	Artificial Reef	Northern Adriatic Sea (Marche region).	Investigated the use of microphytobenthos colonizing Autonomous Reef Monitoring Structures (ARMS) to assess the marine environmental quality. Assess viability of ARMS as AR structures.	ARMS deployed and removed after 13 months to lab. Microphytobenthos total counts were carried out, followed by light microscopy. Diatom analysis was conducted to increase the details for taxonomic identification. Microphytobenthic taxa were identified.	• Inexpensive management
(Yusof, Saad, Nordin, Khodzori, & Husaini, 2015)	Artificial Reef	Bidong Island, Terengganu	Study aims to develop artificial live rocks (ALR) that potentially to be used as one of the alternatives to reduce the overharvesting activity toward natural live rocks.	64 pieces of ALR were deployed. Identification in terms of coral spat species and macrobenthic organisms was done after each retrieval. Coral spat was identified based on the morphology of their columella, septa and corallite wall.	

Author/Company	Type	Location	Rationale	Methodology	Cost
(Blue Corner Marine Research , 2018)	Artificial Reef	Nusa Penida, Indonesia		Diver deployment of steel frames. Harvest coral transplants from parent colonies and broken coral. Attach coral fragments to frames. Monitor growth and mortality of fragments.	
(MARS Incorporated, 2018)	Artificial Reef	Badi Island, Indonesia	• Develop scalable model • Re-establish basic coral reef infrastructure • Increase local marine populations • Provide management and legal framework for long term food security and economic viability	Divers lay down coral rehab element (spiders) on sea floor and join them together to form habitat for new fish and marine life.	
(ReefBall Australia , n.d.)	Artificial Reef (deployments)	Qatar, Canberra (freshwater), Port Arlington/Frankston, Bahrain, Moreton Bay, Gippsland Lakes, Saudi Arabia, Botany Bay, Western Australia, UAE, Cyprus	Increase fish and marine habitat for conservation, recreation and coastal management (breakwaters).		• Transport by barge to site

Author/Company	Type	Location	Rationale	Methodology	Cost
(Dizon, Edwards, & Gomez, 2008)	Transplantation	Bolinao Reef System, Philippines	Experiment compared the performance of three locally available adhesives in attaching nubbins (2–3 cm)	A total of 540 nubbins were collected and transplanted onto giant clam shells, using	• Glues/epoxy can be expensive

Author/Company	Type	Location	Rationale	Methodology	Cost
			of 12 coral species on the shells	different adhesives. Transplants visited every two weeks for 5 months and analysed for mortality, detachment, and self-attachment.	• Issues with mixing and time to set for all glues/epoxy
(Department of Land and Natural Resources, 2006)	*Ex situ* Coral Gardening	Hawaii	Create *ex situ* nursery taking transplanted coral from non-coral reef source to provide protection from disease, water quality issues, aquatic invasive species, predation and competition to create re-combined coral colonies in a short time.	Fast-Growth Protocol begins with the removal of a small coral from somewhere like a harbor piling. It is then quarantined in the nursery before being fragmented into a small living pieces. Each of these genetically-identical fragments are then exposed to optimal light, water and nutrient conditions before being re-aggregated together to create at least a 40 cm colony. Prior to being transplanted back into the ocean it is put in an acclimation tank which duplicates the conditions it will experience once it's transplanted onto the target restoration reef	
(MOTE Marine Laboratory and Aqauirum , n.d.)	Coral Gardening – Micro fragmentation and fusion	Florida, USA	Maintain an underwater nursery growing staghorn corals, a threatened	Raise and study more than 20 species of hard corals, using fragments 'rescued' following boat	

Author/Company	Type	Location	Rationale	Methodology	Cost
			branching coral species that grows relatively quickly.	groundings and other disturbances.	
(Coral Vita, n.d.)			Land-based farms to grow diverse corals resilient to changing ocean conditions. Particularly for eco-tourism	Based on MOTE Marine Lab work.	
(People4Ocean, 2018)	Coral Gardening	Seychelles Mauritius	P4O creates underwater coral nurseries to grow and propagate reefs of the future. We select coral fragments from nearby resilient reefs and allow them to thrive in optimum conditions for wellness and accelerated growth during a period of 12 to 18 months.	Nursery-grown corals are transplanted onto degraded areas to re-establish ecosystem functions and habitat features.	
(University of Technology Sydney , 2018)	Coral Gardening	Great Barrier Reef	Develop new tools that can miniaturise and semi-mechanise “out-planting” of corals from coral nurseries back to the reef to reduce costs. Aid GBR recovery.	Trialling their new tools for miniaturisation and mechanising out-planting.	
(SECORE International , n.d.)	**Sexual coral restoration**	Mexico Curacao	Develop the basic technology to apply sexual coral reproduction for sustainable management of coral populations in public aquaria	SECORE and partners have developed a new concept (SECORE film) that will enable us to seed large numbers of coral recruits without the need to attach each coral by hand (Sowing corals). We are working with leading scientists to	

Author/Company	Type	Location	Rationale	Methodology	Cost
				improve our techniques and develop new ones.	

Author/Company	Type	Location	Rationale	Methodology	Cost
(dela Cruz & Harrison, 2017)	Active Coral Restoration – Larval Supply	Pangasinan, Northern Luzon, Philippines	Test the effect of supplying large numbers of coral larvae on replicate degraded reef areas during a five-day larval settlement period to quantify initial larval settlement and longer-term recruitment outcomes.	Long-term monitoring over three years enabled subsequent patterns of post-settlement survival, growth and onset of sexual reproduction of coral recruits in larval enhanced plots versus control plots without larval provision to be compared	• Total production cost $1654.00, and an average production cost of $20.94 for each of the colonies surviving after 35 months • Chronic disturbances and key threats require management
(The Nature Conservancy , 2018)	Active Coral Restoration – Larval Supply	Virgin Islands	The expedition was part of the TNC's coral conservation initiative to restore reefs across the Caribbean by using cutting-edge science to grow and outplant at scales never possible.	Collect gametes, or bundles of eggs and sperm, from elkhorn corals.	
(James Cook University, 2018)	Active Coral Restoration – Larval Supply	Great Barrier Reef	Harvest millions of coral eggs and sperm to grow new coral larvae that will be released to help restore damaged parts of the Great Barrier Reef	Eggs and sperm combined in enclosures on the reef and in tanks to produce the larvae, then released in damaged parts of the reef.	

Author/Company	Type	Location	Rationale	Methodology	Cost
(Queensland University of Technology , 2018) (Southern Cross University , 2018)	Active Coral Restoration – Larval Supply	Great Barrier Reef	Restoring damaged parts of the Great Barrier Reef and speeding up the recovery of ecosystems affected by coral bleaching	Scientists collect hundreds of millions of coral spawn from the corals that have survived the two recent mass coral bleaching events, reared and redistributed on damaged reef areas using semi-autonomous robot, *LarvalBot*.	
(Edwards A. , 2010)	Substrate Stabilisation – rock piles	Komodo National Park, Indonesia	To repair the damage done to coral reef communities via blast fishing with the specific goal of increasing hard coral coverage, and thus marine biodiversity by stabilising the substrate using low-cost, low-tech techniques.	Limestone rock piles of different designs were installed using approximately 140 m^3 of rock per installation. The rocks were thrown into the water from boats and then rearranged where necessary by divers using SCUBA at depths of 5–10 m. Long-term monitoring of success over six years was undertaken to evaluate success of designs.	• Cost per m^2 of each design was: $US17 for complete coverage; $US5 for spur and groove rows; $US3 for rock piles; Cost of materials, transportation, boat rental, and labour totalled an average $US5/$m^2$
(Edwards A. , 2010)	Substrate Stabilisation – plastic netting	Calagcalag Marine Protected Area, Central Visayas, Philippines	To repair the damage done to coral reef communities via blast fishing with the specific goal to improve coral recruit survival and to kick-start fish habitat re-establishment.	Locally-available plastic mesh (2 cm mesh size), was laid on the rubble and anchored with rebar stakes. Holes cut in the mesh to accommodate existing coral heads acted as additional	• Total budget equalled $US35,000 • The cost of materials and labour for set-up averaged $US 75 per 17.5 m^2 per plot. Lower cost was as a

Author/Company	Type	Location	Rationale	Methodology	Cost
				anchorage. Hollow, pyramid-shaped rock piles were constructed onshore by local fishers using reef rock and cement and positioned on the mesh both to hold it down and provide topographic complexity to attract fish.	result of volunteer assistance. Without assistance, the initial outlay for the 2400 m^2 rubble field to be covered with mesh, would have been an estimated $US 10,560.
(Edwards & Gomez, 2007)	Physical Restoration	Matira Point, Bora Bora, French Polynesia	Both physical and biological restoration was undertaken to restore a reef damaged by sand mining operations. The physical restoration for the project was largely used to facilitate transplantation efforts.	The physical restoration aspect of the project consisted of: the refilling of extraction pits created by dredging operations, the instillation of three groynes and beach nourishment implemented in between the groynes. The shoreline was remodelled, and vegetation replanted. 125 artificial concrete structures were deployed on the surrounding sandy shallow reef flat to act as breakwaters to protect the coast from lagoonal swells.	• Construction of groynes cost $US12,000. • Filling of extraction pits and beach nourishment cost $US445,000. • Coastline profiling and vegetation planting activities cost $US734,000 • Construction and deployment of artificial structures as breakwaters cost $US410,000. Total physical restoration totalled $US1,601,000.
(Jaap, 2000)	Substrate Stabilisation – hollow rocks	Elliott Key, Biscayne National Park	New structures can be fabricated from limestone and/or cement can help to	A concrete hemisphere mimicking a moderate-sized boulder with a hollow interior designed	

Author/Company	Type	Location	Rationale	Methodology	Cost
			restore a damaged coral reef.	as refuge habitat for mobile organisms. Recent improvements to this design include additional openings for improved internal water circulation and limestone rock embedded in the concrete to add rough texture.	
(Westcott, Fletcher, Babcock, & Plaganyi-Lloyd, 2016)	CoTs Management	Great Barrier Reef, Australia	CoTS is a species that, during population outbreaks, can severely damage the coral reef in question and furthermore inhibit natural recruitment. This study aimed to explore how to best manage CoTS.	Looked at two main management techniques; 1.) removing the causes of outbreaks (i.e. nutrients and increased run-off) 2.) single injection methods based on bile salts and vinegar (i.e. manual control).	Early intervention and tailored management depending on local context deemed the most effective way to limit the impact of CoTS on coral and coral recruitment.
(DeMartini, et al., 2013)	Sediment Impact on Coastal Recruitment	Pelekane Bay, west Hawaii Island	To understand the effects of anthropogenic impacts (namely, sedimentation) on the health of coral, including coral recruitment.	Six primary (near-field) impact stations were sited haphazardly along a spatial gradient of presumed diminishing sediment impact. Experimental arrays were used to measure sediment accumulation rate and the recruitment of corals at a series of permanent stations.	Recruit corals were absent from stations closest to the point of discharge. Further, coral recruitment was in some cases twice as great. In general, greater numbers of recruit corals were observed at stations farther offshore and downcoast, beyond

BMT

Author/Company	Type	Location	Rationale	Methodology	Cost
					the region of poor water circulation.
(Fabricius, 2005)	Nutrient run-off	General.	At a local scale water pollution can result in severely lowered water quality. In turn, this water quality impacts the health, resilience and ultimately the recovery of coral following a disturbance event.	An examination of multiple global studies.	Found that generally sedimentation and turbidity-related light limitation has negative consequences for coral recruitment depending on species and circumstances. This occurs because of coral smothering, or by supporting the growth of algae or predatory species.

Appendix I Literature Review of non-market values

Non-market Values for Coastal Ecosystems

Evaluation of the Socio-economic Impacts of Marine Ecosystem Degradation in the Seychelles (2004)

Cesar, H., P. Van Beukering, R. Payet and E. Grandourt, Cesar Environmental Economics Consulting.

This study used contingent valuation, travel cost, and change in productivity valuation techniques to estimate the benefits and costs of marine resources in the Seychelles. The study relied on information from reports and statistics, the literature, unprocessed data, a tourism survey, and a resident survey. The tourism survey was administered to active coral reef users in the Seychelles between August and October 2003. A total of 128 divers, 128 snorkelers, and 94 non-users were interviewed. The resident survey was administered to 478 residents in Victoria and Mahe in September 2003. Fisheries data was obtained from the Seychelles Fishing Authority. Across the total sample, the WTP for funding conservation projects is $4.87, the WTP for a turtle tour is $47.70 and the WTP for a whale shark tour is $54.73 (2005 US Dollars). For all three experiences, the WTP estimates are highest for divers, followed by snorkelers, and then non-users.

Overall, the net present value (NPV) of benefits is $320.2 million for Beau Vallon, $159.4 million for La Digue, $359.5 million for St. Anne, $95.7 million for Curieuse, $31.9 million for Bird Island, and $31.1 million for Port Glaud (US Dollars; currency year not given). The difference in the NPV benefits with and without management (net benefits) ranges from $1.1 million in Port Glaud to $20.84 million in Curieuse. Furthermore, across all sites, the net benefits of adaptation to bleaching are $210 million compared to net adaptation costs of $109 million.

Divers' Willingness to Pay for Improved Coral Reef Conditions in Guam: An Untapped Source of Funding for Management and Conservation? (2016)

Grafeld, S., K. Oleson, M. Barnes, M. Peng, C. Chan and M. Weijerman, Ecological Economics vol. 128, pp. 202-213.

The purpose of this non-market valuation study was to estimate the economic value of various ecological attributes of coral reef ecosystems in Guam to scuba divers. The ecological integrity of coral reefs are threatened by a number of factors, including climate change, sedimentation, over-fishing, and various forms of pollution. Investigating divers' preferences and willingness-to-pay (WTP) for reef attributes can inform policy responses to this depletion. A survey featuring both a choice experiment and a contingent valuation question was administered to 220 divers in August 2013 around Guam. Results indicate that divers have a positive marginal WTP for many reef attributes, including fish biomass, species diversity, and presence of sharks and turtles. The mean marginal WTP per dive (2013 US Dollars) ranged from $3.86 (sharks only) to $35.14 (sharks and turtles) relative to base conditions. Respondents also indicated that they would be willing to contribute on average $10 (one-time) to sediment reduction projects. The results of this study can be used to inform coral reef management and funding decisions in Guam and estimate the economic impacts of divers' WTP for improved reef health.

Estimation of Local Tourists Willingness to Pay (2016)

Faizan, M., A. Sasekumar and S. Chenayah, Regional Studies in Marine Science vol. 7, pp. 142-149.

The objective of this contingent valuation study was to examine local tourists' preferences for alternative coral reef management scenarios in Cape Rachado, Malaysia. A survey was designed utilizing inputs from local

NGOs and other interest groups. Survey respondents were given a description of the current situation of the coral reef at the Cape Rachado and the potential threats to its health. They were then presented with an alternative management scenario that will mitigate these threats, but at a conservation fee charged on their entry fee. Using responses to the valuation question the authors computed a median WTP of 3.00 (MYR, currency year not given) for the alternative coral reef management scenario. The total number of visits to the Cape Rachado was 345,000 (This estimate was obtained by assuming that half of beach visits in Port Dickson were at Cape Rachado). Using the median WTP estimate of MYR 3.00 the annual value estimate for funding the alternative coral reef management scenario was MYR 1,035,000.00 (currency year not given).

Effects of Great Barrier Reef degradation on recreational reef-trip demand: a contingent behaviour approach (2009)

Kragt, M. E., P. C. Roebeling and A. Ruij, Agricultural and Resource Economics, vol. 53, pp. 213-229.

This study estimated the changes in trip demand to the Great Barrier Reef resulting from a decline in reef quality. Information on recreational reef trips was collected a contingent behaviour survey, administered at Great Barrier Reef visitors in Port Douglas. The survey was carried out over a four-week period in September 2004 on board tourism vessels of various commercial operators.

The study found that consumer surplus per recreational reef trip for an average diver or snorkeler is A$184.84 with current reef quality (Australian dollars). The authors found that the visit rate of divers and snorkelers was estimated to decrease by about 80% if reef quality declines to levels presented in the survey. The authors estimated that consumer surplus from reef trips would also decrease by 80% (from A$285 million/year to A$56 million/year). The estimated total expenditure on full-day reef trips would decrease from A$250 million/year to A$50 million/year. The results of this research present valuable input in evaluating the effects of policy measures that influence reef quality and can be used to assess the overall cost effectiveness of coral reef management programs. Funding for this research was provided by the Sustainable Ecosystems division of the Commonwealth Scientific and Industrial Research Organization.

Non-Market Use and Non-Use Values for Preserving Ecosystem Services Over Time: A Choice Experiment Application to Coral Reef Ecosystems in New Caledonia (2015)

Marre, J., L. Brander, O. Thebaud, J. Boncoeur, S. Pascoe, L. Coglan and N. Pascal, Ocean and Coastal Management Vol 105, pp. 1-14.

The purpose of this stated preference study was to determine the value of preserving coral reef ecosystems in New Caledonia. Additionally, the study sought to partition the total value of users into use and non-use values. Four attributes were modelled; quantity of animals fished, health and richness of marine life, coastal and lagoon natural landscapes, and areas of practice.

A choice experiment survey was administered in-person to a sample of 550 residents in two different study regions of New Caledonia between November 2011 and February 2012, generating 434 useable responses. Including only responses from participants who stated attendance to the payment attribute, results suggest that residents have significant values for the four different specified attributes of marine ecosystems in each of the study regions. Mean monthly willingness-to-pay (WTP) per person for the logarithm for one year of preservation ranged from 252 CFP (2013 Pacific Francs) for preservation of coastal and marine landscapes to 1297 CFP for preservation of areas of practice and activity in the VKP (northern) study region. The study suggests that between 25 and 40% of the total value reported by marine ecosystem users for various attributes can be assigned to non-use value.

Valuing Recreational Benefits of Coral Reefs: The Case of Mombasa Marine National Park and Reserve, Kenya (2010)

Ransom, K. P. and S. C. Mangi, Environmental Management 45, no. 1, pp. 145-154.

This contingent valuation (CV) study estimated the recreation benefits from coral reefs in Kenya's Mombasa Marine National Park and Reserve. The survey was administered via interviews conducted in October and December 2007. The response rate was 94% and a total of 285 adult visitors were surveyed. A total of 221 surveys were included in the analysis.

The mean willingness-to-pay (WTP) for a glass bottom boat snorkel trip to the park was $2.2 for Kenyan citizens and $8.4 for foreigners (US Dollars; currency year not given). The mean WTP for glass bottom boat snorkel trip to the reserve was $9.6 for foreigners and the mean WTP for a park diving trip was $5.9 for foreigners. Aggregated over the number of visitors, the total annual WTP is estimated at $346,733 per year. These WTP results are in addition to the current park entrance fees. The results suggest that visitors are willing to pay additional fees at recreational sites to support conservation programs.

Valuing Marine and Coastal Ecosystem Service Benefits: Case Study of St Vincent and the Grenadines' Proposed Marine Protected Areas (2015)

Christie, M., K. Remoundou, E. Siwicka and W. Wainwright, Ecosystem Services Vol 11, pp. 115-127.

The purpose of this stated preference study was to estimate the value of marine and coastal ecosystem service benefits to both locals and tourists in two proposed marine protected areas (MPAs) of St Vincent and the Grenadines. Marine and coastal ecosystems in St Vincent and the Grenadines are currently threatened by waste disposal, deforestation, land degradation, tourism development, and over-exploitation of biodiversity. A choice experiment survey was administered to 710 people, both locals and tourists, at the two sites in 2012 and 2013, in order to elicit value for six different ecosystem services. Results indicate that both locals and tourists are willing to pay to both avoid future declines to as well as improve all services in both MPAs.

Six ecosystem services were valued at each of the two proposed marine protected areas (MPAs): fishing, coastal protection, human health, ecosystem resilience, beach recreation, and diving/snorkelling. In each of the proposed MPAs, each service had a 'decline' (baseline situation, ie., what would happen with no additional protection), 'current' (status quo level), and 'improve' scenario level, and an associated rating out of 5 (5 being the best).

The total household annual WTP to avoid a decline in all six services in the South Coast was $56.52 (US Dollars) and $113.05 for locals and tourists, respectively. The WTP to improve all six ecosystem services was $54.41 and $88.48, respectively. The WTP to avoid a decline in all services in Tobago Cay was estimated to be $41.21 and $89.11 for locals and tourists, respectively; conversely, the WTP to improve all services was $29.36 and $77.07, respectively.

The Cost of Mediterranean Sea Warming and Acidification: A Choice Experiment Among Scuba Divers at Medes Islands, Spain

Rodrigues, L. C., J. CJM. Van den Bergh, M. L. Loureiro, P. ALD. Nunes and S. Rossi, Environmental and Resource Economics Vol. 63, no. 2, pp. 289-311.

This choice experiment was undertaken to elicit preferences of scuba divers regarding the quality of diving areas with Coralligenous marine habitat in the Marine Protected Area of Medes Islands (Spain). The particular

Mediterranean habitat is under threat due to climate change and ocean acidification. If no protection occurs, there is an expected abundance of stinging jelly fish. All gorgonians disappear due to climate change and ocean acidification and there are no vertical walls or caves/tunnels, only hard bottoms with boulders on the underwater landscape.

From a total of 587 scuba divers asked to participate in the study (face-to-face), 432 completed the survey (a response rate of 73.6%). Estimates of welfare values showed that the local extinction of gorgonians had the highest negative effect on utility equivalent to a cost of 60 per dive, followed by abundance of stinging jellyfish with a cost of 26 per dive (2013 €). Overall, results indicated a decrease in the attractiveness of Coralligenous areas for scuba diving as a result of both environmental pressures. This study concludes that based on the results of the choice experiment the environmental changes associated with sea warming and ocean acidification may reduce the attractiveness of Mediterranean Coralligenous areas for tourists and scuba diving.

Recreational SCUBA Divers Willingness to Pay for Marine Biodiversity in Barbados (2013)

Schuhmann, P.W., J.F. Casey, J.A. Horrocks and H.A. Oxenford, Journal of Environmental Management 121, pp. 29-36.

The choice experiment elicited recreational SCUBA divers Willingness to Pay (WTP) for quality improvements in dive characteristics (live coral cover, fish species diversity, other divers, encounters with sea turtles and prices paid for dives) in Barbados. The threats were related to over fishing, sea surfacing warming, coastal construction, beach erosion etc. 165 recreational SCUBA divers were interviewed in Barbados between July 2007 and April 2009. WTP for good marine biodiversity was significantly higher than prices paid for dives. The WTP for improving coral cover from 15% to 25% was roughly $US41 per two tank dive. The estimates for encounters with sea turtles suggest that divers were willing to pay over $US57 for the first encounter, and approximately $US20 per 2-tank dive for each additional encounter. These results could inform management decisions regarding reef use and sea turtle conservation.

Willingness to Pay for Marine-Based Tourism in the Ponta do Ouro Partial Marine Reserve, Mozambique (2015)

Daly, C.A.K, G. Fraser, and J.D. Snowball, African Journal of Marine Science 37, no.1, pp 33-40.

This study explored the opportunity for a user pay system to partially finance multi use Marine Protected Areas by applying contingent valuation method to Ponta do Ouro Partial Marine Reserve, Mozambique. The main survey was conducted in November 2012 to April 2013 and stratified sampling was used to avoid selection bias. A total of 120 questionnaires were administered at 2 tourist hubs within the reserve. Visual cue cards were used together with the questionnaire. Respondents were asked their willingness to pay a user fee to access a protected area. The elicitation method used was a 20 cell payment card with incremental threshold values between R1 and R200. Mean willingness to pay for accessing the Ponta do Ouro Partial Marine Reserve was R43.75 (2015 South African rands) per person per day. Based on this fee amount, the estimated annual revenues ranged between R1.46 million to R3.3 million. Respective mean willingness to pay for SCUBA divers, dolphin tourists and anglers were R45.20, R41.70 and R39.70. Values estimated were an indication of the value of the marine protected area which could be jeopardized if the proposed deep-water port construction proceeded.

Willingness to Pay for Environmental Preservation by Ecotourism-Linked Businesses: Evidence from the Caribbean Windward Islands (2003)

Allport, R.C. and J.E. Epperson, Faculty Series, FS 03-01, Department of Agricultural and Applied Economics, College of Agricultural and Environmental Sciences, University of Georgia.

An open-ended contingent valuation method was used to estimate the annual willingness to pay (WTP) of businesses directly dependent on ecotourism for the maintenance of ecotourism sites in four Windward Islands in the Caribbean Region which face environmental problems associated with the growth in tourism such as erosion of beaches, the destruction of coral reefs, marine and coastal pollution from watersports, the dumping of waste and untreated sewage. Data was based on a CV survey conducted in June 1999 to June 2000 of a sample of businesses drawn by stratified random sampling from a list of all businesses that provided ecotourism experiences within the four Windward Islands. The survey was conducted using a combination of in-person interviews and elicitation by mail with follow-up by telephone. WTP was modelled using a Tobit model as a function of the business and socioeconomic characteristics and the environmental policies of the respondent firms. The annual WTP of businesses for the maintenance of ecotourism sites ranged from EC$0 to EC$1,200 with a mean of EC$177.04 and a SD of EC$321.49 (EC$2.71 = $US1, average June 1999-June 2000).

Non-market Values for Beach Protection

Contingent Valuation Analysis of Willingness to Pay for Beach Erosion Control Through the Stabiplage Technique: A Study in Djerba (Tunisia) (2017)

Dribek, A., and L. Voltaire, Marine Policy 86, pp. 17-23.

This contingent valuation (CV) study estimated willingness to pay (WTP) for beach erosion control in Djerba, Tunisia. Beaches in the area are degrading due to natural and development-induced causes of erosion. The survey was administered to 256 residents and 218 tourists in Aghir using a combination of phone and face-to-face interviews. Residents and tourists were both willing to pay an average of nearly 9 TND (2008 Tunisian Dinars) per month to stop beach erosion by implementing the stabiplage technique. Aggregated to the total number of residents and visitors, the total WTP values ranged between 133,459 TND (median value) for residents and 5,180,269 TND (mean value) for tourists.

How Does the Social Benefit and Economic Expenditures Generated by a Rural Beach Compare with its Sediment Replacement Cost? (2014)

Feagin, R. A., A. M. Williams, M. L. Martinez and O. Perez-Maqueo, Ocean & Coastal Management 89, no. 89, pp. 79-87.

The purpose of this questionnaire based study was to assess the economic returns and social benefit of Matagorda Beach on East Matagorda Peninsula, Texas; use values and replacement cost of sediment were used to achieve this purpose. The target study population was beach users. A survey with three sections: Demographic Data, Perspectives and Opinions, and Economic Valuations was implemented for 113 groups or individual beach users in the Matagorda beach area over 13 days of sampling in 2009. Data was collected for the survey during three periods: In Season, Off Season, and Spring Break. One person per group was asked to fill out the survey, and respondents were approached by researchers either while on foot or in their vehicles near the beach.

The average use value per person was $1,200.68 (2010 US Dollars). The average was the lowest during Off Season at $665.43 per trip and highest for Spring Break respondents at $1,646.59 per trip. The total expenditures ($2.4 million and $17.7 million) generated by Matagorda beach outweighs the cost of replacing its sediment ($1,972,235.46).

Estimating the nonmarket economic benefits of beach resource management in southeast Queensland, Australia (2014)

Windle, J. and J. Rolfe, Australasian Journal of Environmental Management 21, no. 1, pp. 65-82.

This study conducted stated preference experiments using an online survey of Brisbane residents. The study explored the relative importance of providing public facilities and services at beaches in well populated areas in southeast Queensland using a choice modelling experiment. The study also assessed the economic value associated with managing the problem of substantial beach erosion in southeast Queensland, with a contingent valuation experiment. Results from the choice experiment show that respondents were willing to pay $25.98 (per household per year for three years, in 2012 Australian dollars) for toilet facilities to be provided at a beach. Having a lifeguard on duty had the highest WTP value of $36.12. Respondents were also willing to pay $19.64 to have beaches mechanically cleaned on a monthly basis. Contingent valuation results show that the mean WTP per household for reduction in beach erosion was $101.

Eliciting Beach Users' Willingness to Pay for Protecting European Beaches from Beachrock Processes (2014)

Kontogianni, A., D. Damigos, Ch. Tourkolias, M. Vousdoukas, A. Velegrakis, B. Zanou and M. Skourtos, Ocean & Coastal Management 98, pp. 167-175.

This article assesses beach users' willingness to pay for protecting European beaches from beachrock processes. An open-ended CV survey was conducted to elicit WTP values from beach users in Vatera and Plomari beaches of Lesvos Island, Greece, in august 2005. The sample selected was restricted to European tourists. 106 European tourists were face-to-face interviewed. Almost half of the respondents would be willing to pay an annual tax in the range of €13.2-€16.4 per household. Authors conclude that the findings of the study are of importance to other researchers and decision-makers as a first step towards the understanding of social attitudes and beliefs linked to public's willingness to pay for avoiding beachrock expansion and beach deterioration.

Valuing the Benefits of Beach Protection Measures in the Face of Climate Change: a French Case-study (2013)

Rulleau, B. and H. Rey-Valette, Journal of Environmental Economics and Policy 2, no. 2, pp. 133-147.

The objective of this article is to assess the understanding, expectations, preferences and behaviour concerning beach functions and adaptation measures, while addressing increasing beach erosion and sea level rise due to climate change. Surveys were carried out on 881 full-time and secondary residents, tourists and day-trippers affected by the maintenance and protection of beaches within a pilot zone in the Languedoc-Roussillon coastline in 2009. A contingent valuation method was used, based on a scenario, which put the Intergovernmental Panel on Climate Change (IPCC) hypotheses of a predicted sea level rise into context. Questions on uses and practices, perceptions of risk and preferences concerning management and allowed the estimation of willingness to pay.

Mean WTP is €36.4 per household per year and those more connected to the sea front such as residents have a predictably higher WTP. Similarly, the proportion of interviewees favourable to strategic retreat is inversely related to people's attachment to beach proximity. Importantly variables related to risk perception have a higher impact on WTP than personal or household characteristics.

Economic valuation of preventing beach erosion: comparing existing and non-existing beach markets with stated and revealed preferences (2013)

Logar, I. and J.C.J.M. van den Bergh, Journal of Environmental Economics and Policy, vol. 3, no.1, pp. 44-66.

This study was undertaken on two beaches in Crikvenica, Croatia using the contingent valuation and the travel cost. The purpose of the study was to estimate the willingness to pay a beach entry fee (or higher fee) to prevent beach erosion on beaches during the summer months over the next 10 years. Face-to-face surveys were carried out using systematic sampling which targeted every tenth beach user. 745 surveys were carried out in total, with 379 carried out on the free beach and 366 at the paid beach. Response rates were 69% and 79%, respectively. Surveys were carried out in July 2008.

Based on the initial (follow-up) valuation question, the stated WTP per adult per day for avoiding beach erosion equals €1.69 (€1.26) for the paid beach and €2.08 (€1.84) for the free beach. In addition, the travel cost method is employed. It reveals that consumer surpluses for visiting the paid and the free beach amount to €2.57 and €1.74, respectively. This study indicates that beach entrance fees might be a useful tool for raising the funds required for beach preservation.

ICZM and Coastal Defence Perception by Beach Users: Lessons from the Mediterranean Coastal Area (2011)

Koutrakis, E., A. Sapounidis, S. Marzetti, V. Marin, S. Roussel, S. Martino, M. Fabiano, C. Paoli, H. Rey-Valette, D. Povh and C. G. Malvárez, Ocean & Coastal Management, vol. 54, pp. 821-830.

A contingent survey was carried out in five Mediterranean sites (in Greece, Italy and France) in order to elicit visitors Willingness-to-Pay (WTP) for beach defense against coastal erosion (anthropogenic or natural). Beach visitors included residents, day-visitors and tourists, aged 18 plus and the survey was implemented through face-to-face interviews, of approximately 15 minute. A total of 1462 questionnaires were completed. Mean WTP (2007 €) for beach defense against coastal erosion in the five sites under study was calculated.

The daily mean WTPs (zero included) ranged from €0.5 to €1.49 per day in the regions who estimated use values. The highest mean use value per day was found for Nestos Delta in the East Macedonia & Thrace Region. With regard to non-use values, in the Emilia-Romagna Region, visitors were willing to donate on average €1.1 every five years for a beach defense project. The survey yielded important information for coastal and beach managers showing that respondents recognize the need to fund the management of beaches.

When the Tide is High: Estimating the Welfare Impact of Coastal Erosion Management (2011)

Phillips, Y. Paper presented at the 2011 NZARES Conference. Nelson, New Zealand.

The purpose of this choice modelling study was to assess the welfare impacts of various beach management options at Buffalo Beach in New Zealand. Currently, Buffalo Beach suffers from the risk of erosion and flooding. The survey was administered through in-person interviews at Buffalo Beach between 7am and 8pm on a single weekend in January 2011. A total of 119 people completed the survey including 19 residents and 100 visitors.

In December 2010, three focus groups were held in Whitianga to assess perceptions of coastal erosion and management options.

The annual willingness-to-pay (WTP) estimates for residents (visitors) ranged from a low of -$132.20 (-$99.29) for a 100% frontal seawall to a high of $184.35 ($64.62) to reduce the flooding risk to low risk (New Zealand Dollars, currency year not given). The aggregate compensating variation estimates for possible coastal management scenarios ranged from a low of negative $1.6 million per year to develop the middle section of Buffalo Beach to a high of $1.3 million per year for a managed retreat at the north end of Buffalo Beach. Results suggest that rock seawalls have a large public disamenity value and there are high public benefits of implementing a managed retreat at the north end of Buffalo Beach.

Valuing Beach Recreation Across a Regional Area: The Great Barrier Reef in Australia (2012)

Rolfe, J. and D. Gregg, Ocean & Coastal Management 69, pp. 282-290.

This study surveyed 1049 residents living within 50km of the Northern Queensland coastline adjacent to the Great Barrier Reef to assess beach recreation values for the local population. Approximately 800,000 people are residents of this area. The population was grouped into 6 regional areas: Bundaberg, Gladstone, Capricorn, Mackay, Townsville and Cairns. Travel costs were estimated and negative binomial models were used to estimate visitation rate and recreation values.

The value of a single beach visit was estimated at $35.09 (AUD) per person and the aggregate value across the population was estimated at $587.3 million per year. Contingent behaviour models were used to estimate the effects of declining water quality, with the marginal effects assessed at $1.30 per recreation trip to avoid a 1% decline in water quality.

Non-market Values for Fishing

Valuation and Analysis of Boat-based Recreational Fishing in Western Australia (2014)

Hailu, A., A. Jegnie and M. Burton, Paper presented at the 5th World Congress of Environmental and Resource Economists, 28 June - 2 July 2014, Istanbul, Turkey.

The purpose of this travel cost study was to estimate the welfare impacts of different bag limit policies and loss of site access for recreational fisherman in Western Australia. The study valued 5 bag limit policies compared to base policy of no limits. The study uses data taken from the National Survey of Recreational Fishing (NSRF) that was conducted by WA Department of Fisheries in 2000-2001. The survey focuses on non-commercial fisheries and gathered information on fishing sites, primary and secondary target species, fishing hours and date of trips, catch details, fishing method, fishing party size, driving distance, fishing mode, fishing waterbody type, and shore type. The study estimated a catch rate model to estimate the impacts of different bag limit policies.

On a per trip basis, an angler household suffers an average loss between $18.5 and $33.5 under the bag limit policies (Australian Dollars, currency year not given). These per trip values translate into mean annual losses of between $118.20 and $212.50. The access values are highest at Albany ($9.49 to $12.84) and lowest at Burns Beach ($0.00 to $0.05). The results can be used by resource managers to set bag limit policies more effectively.

Cultural Bequest Values for Ecosystem Service Flows Among Indigenous Fishers: A Discrete Choice Experiment Validated with Mixed Methods (2015)

Oleson, K. L., M. Barnes, L. M. Brander, T. A. Oliver, I. Van Beek, B. Zafindrasilivonona and P. Van Beukering, Ecological Economics vol. 114, pp. 104-116.

This choice experiment (CE) study measured the value of improvements to the Velondriake locally managed marine area (LMMA) in Madagascar. The area is relied upon by the Vezo people, whose livelihoods depend on the fishery which has been declining in quality due to developmental and population pressures. The survey was administered by interviewing 258 respondents living in the region of the Velondriake LMMA with a 95% response rate, though 63 responses were removed due to respondents not understanding the CE exercise. Respondents were willing to pay 24,420 Malagasy Ariary (MGA, 2010 currency year) to increase the generations of people able to live as Vezo from one to two generations, and 56,780 MGA to increase this from one generation to five generations. Respondents were also willing to pay 6180 MGA to increase future fishery profits from the baseline of 60,000 MGA per household per year to 70,000 MGA, and were willing to pay 14,050 MGA to increase these future profits to 80,000 MGA per year. Shoreline protection was also important, with the average WTP of 15,000 MGA for decreasing the amount of times home repair is required from once every three years to once every five years. The authors note that cultural bequest values are of high importance when considering ecosystem services.

Economic Valuation of Recreational Fishing in Western Australia (2010)

Raguragavan, J., A. Hailu and M. Burton, Working Paper 1001, School of Agricultural and Resource Economics, The University of Western Australia.

A travel cost method was used to determine the value of recreational fishing of all the eight major fishing regions and 48 fishing sites in Western Australia (WA). Data from the 2000/2001 National Survey of Recreational Fishing (NSRF) of the Department of Fisheries, WA, in particular, a subset of the data from the log book survey was utilized. The sample included 778 anglers who made a total of 4008 fishing trips to all the fishing regions in WA. A multinomial logit random utility model of site choice and a negative binomial econometric model of angler and fish-specific expected catch rates were estimated separately for five fish types. Welfare measures were estimated for the different fish types, a 100% increase in catch rates, and site access values.

The monetary value of a fish caught by recreational fishers in Western Australia (WA) ranged from $2.28 for butter fish to $15.94 for prize fish. For a 100% increase in the expected catch rates, anglers, on average, would be willing to pay from about $14.88 for table fish to $31.41 for prize fish, with the high value fish type getting higher CV values. The mean access values or welfare losses from site closure amounted to $3.81 per trip across all anglers and $5.61 for anglers who actually fished in the affected site. The aggregate annual access value of fishing sites in WA was estimated at $20.38 million. The study demonstrated that it is possible to generate estimates for the value of recreational fishing that is based on theoretically consistent procedures and empirical data to support resource management decisions in WA.

Low-Income Fishermen's Willingness-to-Pay for Fisheries and Watershed Management: An Application of Choice Experiment to Lake Tana, Ethiopia (2011)

Agimass, F. and A. Mekonnen, Ecological Economics 71, pp. 162-170.

For this choice experiment, 166 local fishermen, most belonging to local fishing associations, were surveyed face-to-face to find out their willingness to pay for alternative fish harvesting management scenarios for Lake Tana, Ethiopia. The monthly willingness to pay for moderate management scenario was 57 Ethiopian birr ($US5.3), and 93 birr ($US8.6) for aggressive management scenario. Respondents were willing to pay about 15 birr monthly for an increase in fishing control from no control and pay 50% more for an increase in lakeside plantation from status quo. The study found that fishermen, although having low income, were willing to spend money for better management of Lake Tana.

Appendix J Request for Information

Secondary outcomes/benefits	Unit	Source	Year
Visitation (tourism and local)			
Current visitation to reef (tourists)			
Divers	No/year		
Snorkelers	No/year		
Recreational fishing	No/year		
Projected growth in visitation (without intervention)	% per annum		
Current visitation to reef (local residents)			
Divers	No/year		
Snorkelers	No/year		
Recreational fishing	No/year		
Projected growth in visitation (without intervention)	% per annum		
Current visitation to beach (tourists)			
Day trip	No/year		
Overnight stay in local area	No/year		
Projected growth in visitation (without intervention)	% per annum		
Current visitation to beach (residents)			
Recreational visits to beach	No/year		
Projected growth in visitation (without intervention)	% per annum		
Assumed impact of change in reef/beach condition on visitation			
Additional visitors to reef	No/year		
Additional visitors to beach	No/year		
Substitutability			
How many reefs in equal condition are easily accessible (after intervention)	No		
How many beaches in equal condition are easily accessible (after intervention)	No		
Ecosystem services			
Non-commercial fishing (artisanal)			
Current number undertaking non-commercial fishing (artisanal)	No.		
Current types of fish/shellfish caught	Description		
Current average volume caught	tonnes		
Types of fish/shellfish caught after intervention	Description		
Average volume caught after intervention	tonnes		

Secondary outcomes/benefits	Unit	Source	Year
Commercial fishing (including aquaculture)			
Current number undertaking commercial fishing	No.		
Current types of fish/shellfish caught	Description		
Current average volume caught	tonnes		
Types of fish/shellfish caught after intervention	Description		
Average volume caught after intervention	tonnes		
Other resource extraction (including aquaculture)			
Number undertaking	No.		
Types of resources	Description		
Average volume	tonnes		
Type of resources available after intervention	Description		
Volume of resource extraction after intervention	tonnes		
Other ecosystem services			
Current seagrass extent/condition	ha		
Current mangrove extent/condition	ha		
Current wetland extent/condition	ha		
Extent of seagrass after intervention /condition	ha		
Extent of mangroves after intervention /condition	ha		
Extent of wetlands after intervention /condition	ha		
Damages / protection			
Residential			
Residential properties	No.		
Projected growth in residential properties	%		
Average property value	$		
Current proportion affected by flooding	%		
Proportion affected by flooding after intervention	%		
Commercial			
Commercial properties	No.		
Projected growth in commercial properties	%		
Average property value	$		
Current proportion affected by flooding	%		
Proportion affected by flooding after intervention	%		
Infrastructure e.g. roads			
Type	Description		
Current extent affected by flooding	Km		

Secondary outcomes/benefits	Unit	Source	Year
Extent affected by flooding after intervention	km		
Value	$		
Non-use			
Population			
Local population	No.		
Projected population growth	% per annum		

Appendix K Financing Assessment Framework

Table K-1 Indicative assessment criteria that impact finance/funding options (Banhalmi-Zakar 2016)

Feature	Spectrum		
Size/capital requirement	Small (<$25 million)	Medium ($25-$50 million)	Large ($50+ million)
Lifespan of project/initiative	Short-term (now to 2030)	Medium-term (2030-2070)	Long-term (beyond 2070)
Physicality	Soft measure/initiative (e.g. plan, community capacity building, etc.)	Scheme (e.g. partnership)	Engineered structure
Discreteness	Part of new structure	Upgrading existing structure	New stand-alone investment
Ownership	Local government	Public-private-partnership	Private
Scalability	Not scalable	Scalable to some extent	Scalable to a large extent
Beneficiaries	Single/few company/individuals	Some (countable)	Many/wider community
Financial return	Unable to generate	Able to generate, unable to distinguish/quantify	Calculable and demonstrable
Return on investment timescale	Short-term (>2 years)	Medium-term (2-7 years)	Long-term (7+ years)
Risk reduction	Difficult to demonstrate risk reduction	Small-scale risk reduction compared to overall project/business	Demonstrated ability to reduce substantial risk
Insurability	Uninsurable	Partly insurable	Insurable

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