Ecosystem Services Supply, Demand and Values at Petit Barbarons, Seychelles

Ecosystem-based Adaptation through South-South Cooperation (EbA South)

Final Report

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2 INTRODUCTION

The project "Ecosystem-based Adaptation through South-South Cooperation (EbA South)[1]" is supporting ecosystem-based adaptation (EbA) for climate change risks in several countries. Ecofutures was engaged to support the Seychelles (one of the pilot countries) to undertake:

- An assessment of ecosystem service changes for a range of ecosystem-based adaptation and engineered interventions directed at mitigating climate change risks.
- A cost benefit analysis of the adaptation interventions, using the above ecosystem services analysis, project costs and expert opinion.

The objective of the work was to highlight the implications of different climate change adaptation scenarios.

The project undertook a number of engineered and ecosystem-based adaptation interventions in the Seychelles to address climate change risk. One such area was Petit Barbarons, on Mahe, which was a residential area experiencing regular flooding for high rainfall event. This assessment analyses the impacts of the interventions at Petit Barbarons as a case study of the Seychelles EbA activities. The interventions were led by both the Government of Seychelles and EbA South project.

3 ECOSYSTEM SERVICES A BASIS FOR ANALYSIS

Ecosystem services are the outputs of nature that generate services for people. Ecosystem services are the flows generated by the stock of natural capital. It is important to note that ecosystem services are not the same as ecosystem functions. Functions are the biological, chemical, and physical processes associated with natural ecosystems. Services are the results or outputs of those processes which people use - directly or indirectly, to generate benefits.

We are familiar with piped water, sewage treatment and road access as services, but often neglect to recognise nature's processes as beneficial services. In the past, the Seychelles had a comfortable climate with reliable rainfall and a productive ocean, with little or no concern about their future supply. However, that is changing, with services such as climate stability, stable shorelines, coral reef fish stocks and water security now becoming variable and/or uncertain, with threats to associated quality of life. A decline of these services threatens Seychellois society, and the maintenance of ecosystem services is now becoming a major economic and social focus.

In order to predict the possible changes to ecosystem services, through in-action or ecosystem-based adaptation or engineered interventions, the Ecofutures process was employed. This process combines both available data and local wisdom, in a participatory modelling workshop, to understand system linkages and to predict future changes in the social-ecological system. The process included the development of a systems model (using Excel) to outline and understand the status-quo situation at Petit

[1] The project Ecosystem-based Adaptation through South-South Cooperation (EbA South) is a full-sized GEF project, funded through the Special Climate Change Fund. Officially known under the title "Enhancing Capacity, Knowledge and Technology Support to Build Climate Resilience of Vulnerable Developing Countries", the project is implemented by UN Environment and executed by the National Development and Reform Commission of China, NDRC, through the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, IGSNRR, CAS.

Barbarons in terms of ecosystem services, and then modelled the implications of several scenarios that could emerge in Mahé, Seychelles. The modelling process served to provide indicators of:

- The stock of natural capital (terrestrial, estuarine, freshwater and marine) within an impact area at Petit Barbarons (see Figure 1 for the location of the area)
- The range of ecosystem services supplied and their *relative* supply levels (service supply levels are computed as an index relative to other services, for example, the modelling identifies which services are supplied at high, medium and low levels relative to each other)
- The number of ecosystem service users and the benefits generated through their respective use
- The direction and magnitude of ecosystem services change in different climate adaptation scenarios
- The impacts of different intervention scenarios on climate change risk

The process uses ecosystem services as the medium or currency of measuring change, as it is through changes in ecosystem services that humans experience landscape or marine changes. The indicators of change should be used, in conjunction with the cost benefit analysis, to inform approaches to climate change adaptation.

4 THE MODELLING PROCESS EMPLOYED FOR PETIT BARBARONS

A participatory modelling process was planned, that would involve a wide range of stakeholders in assessing the supply of and demand for ecosystem services at Petit Barbarons for a range of future scenarios. However, this was not possible for various reasons, and instead the modelling process was informed by a series of meetings, field observations, published literature and a Climate Adaptation & Management Section[2] workshop. The process used is outlined below:

- Collate basic data on land cover in Petit Barbarons into a Geographic Information System.
- Review published papers, Seychelles Government documents and project reports to inform the modelling.
- Meeting with University of Seychelles staff to discuss the approach.
- Undertake a field assessment of the area to assess the condition of habitats, hydrological linkages and the demand for ecosystem services.
- Build a social-ecological systems model using Excel.
- Map the land cover types and the marine habitat types to determine the geographic location and size (in hectares).
- Demarcate the boundaries of the impact area. Discussions and project reports[3] were used to inform the boundaries of the impact area.
- Develop a suite of climate change adaptation scenarios based on project reports and discussions with University of Seychelles.
- Hold an agent-based modelling workshop with the Climate Adaptation & Management Section. The workshop process reviewed the model inputs, shared understandings of the affected area and interventions, and developed new insights in terms of:
    - The composition, size and condition of the stock of natural capital (the different habitat types)
    - Ecosystem services supply potentials for the different categories of natural capital (forests, estuaries, coral reefs, mangroves, foreshore vegetation, etc) and other built land cover (such as settlements and drains).
    - Ecosystem services supply levels per land cover type.
    - The demand for ecosystem services, including:
        - The numbers of service users.
        - The relative dependence of users on specific services.
- A baseline model was established representing the status quo. Thereafter the workshop evaluated the changes to service supply levels in future scenarios for 2028. A ten-year time horizon was employed to encourage the participants to imagine the most realistic scenarios. The following scenarios were developed:
    - A no-intervention scenario – what could the affected area be like in 2028 without any interventions and with climate change impacts.

[2] The CAMS is the department of the Ministry of Environment, Energy and Climate Change in charge of climate change-related matters.

[3] Henriette, E. et.al. 2017. Enhancing capacity, knowledge and technology support to build climate resilience of vulnerable developing countries. Ecosystem-based Adaptation through South-South Corporation (EbA South). Seychelles Pilot Project Progress Report 7: July - December 2017.

    - The project intervention scenario – what could the affected area be like in 2028 with the mangrove restoration and drains, and with climate change impacts.
    - The project interventions combined with catchment management – combining the project intervention scenario with upstream catchment management.
    - A no maintenance scenario – the project intervention scenario but without any ongoing maintenance.

  The discussion on scenarios included:
    - Switching the allocation of areas between different land cover types, such as reducing wetlands and forests and increasing mangroves and settlement areas.
    - Changing the condition or state of the marine, freshwater and terrestrial habitat types, to respond to interventions, climate change, human pressures and changes in other habitat conditions.
    - Systematically reflecting on the consequences of changes in the terrestrial or marine system in relation to hydrological perturbations, such as when the culverts elevated the flow of marine water into the mangroves or into the wetlands.
    - All the changes were reflected as areas changes (in hectares) or as condition changes (as scores) or both.
- The outcomes, in terms of services supply and demand, were then modelled and reviewed. Any anomalies were discussed and either accepted, or if required, changes were made to the criteria scores to address anomalies.
    - The process generated a common mental model of the Petit Barbarons social-ecological system for the status quo, and then for several plausible scenarios.
    - The process facilitated a vibrant discussion on conditions and numbers of users, and the likely changes in future land uses/cover.
- The stakeholder workshop was undertaken on the 19th July 2018 in Victoria and included the following participants.

Name and area of expertise	**Organisation**
Jean Claude Labrosse – wetlands and rivers background, community, planning.	Climate Adaptation & Management Section
Hendrick Figaro – transport, drainage, community	Climate Adaptation & Management Section
Cynthia Peton – coastal zone	Climate Adaptation & Management Section
Allison Lucas – drainage areas	Climate Adaptation & Management Section
Sharifa Arissol – wetland areas	Climate Adaptation & Management Section
Nigel Simeon – planning and coastal	Climate Adaptation & Management Section
Annie Simeon – coastal zone management	Climate Adaptation & Management Section
Murugaiyan Pugazhendhi – overall coordination	Climate Adaptation & Management Section

- The modelling outcomes are a product of the discussions of the above group, published papers, a meeting with University of Seychelles (Kelly Hoareau, Rowana Walton and Jerome Harlay), GIS analysis (Jemima Bijoux) and field observations with the report reflecting the opinions and perspectives of the information sources.

5 Petit Barbarons natural capital and the ecosystem services supplied

For modelling purposes, a locality map was developed with key land cover or habitat types illustrated (see Figure 1). The impact area was the area identified by Henriette et al 2017, but with an upstream river and forest buffer added. Note that Henriette et al 2017[4] identified an area in the north bay of the bay, and this analysis, the area was subdivided into several marine habitat types. The broad land covers were further divided into the following habitats or land cover types:

- Forest - closed canopy forest with both native and invasive alien plant species, upstream of the residential area, and adjacent to the river
- Wetlands – low-lying areas permanently or temporarily inundated by water identified by Henriette et al 2017
- Built-up urban settlement - urban areas, containing residential, commercial, tourism, and extensive transport services land cover immediately adjacent to the wetlands and drainage lines involving some 25 houses
- Canals/drains – canal, drains and culverts built by the EbA initiative and the Seychelles Government
- River - a 10 meter-wide zone that includes the perennial rivers and their associated river banks, upstream of the residential area
- Mangroves – inter-tidal mangroves, and including the restored mangroves downstream of the residential area
- Seagrass – emergent and subtidal seagrass beds within the northern part of the bay (as identified by Henriette et al 2017)
- Coral debris algae reef - emergent and subtidal coral debris algae reefs within the northern part of the bay
- Coral reef – subtidal coral reefs within the northern part of the bay
- Neritic zone – offshore deep water with a sandy bottom within the northern part of the bay
- Rocky shore – intertidal and exposed rocky shoreline within the northern part of the bay
- Sandy Beach – intertidal sandy shores, from the foredune vegetation to the low water mark within the northern part of the bay
- Foreshore vegetation – above the high-water mark, and including the restored vegetation adjacent to the residential area

The relative stock or sizes of the landscape and marine assets are illustrated in Figure 2. The landcover categories include both natural assets and relevant built assets. In terms of natural assets, the focus was on renewable natural assets which, if managed and used sustainably, have the capacity to regenerate themselves, providing benefits and reducing climate change risks to people in perpetuity. Note that assets such settlements also contain ecological and hydrological processes which benefit society, such as food and water quality maintenance. The study did not consider non-renewable natural assets (e.g. subsurface oil, gas, minerals and aggregates).

The condition or state of the stock of natural assets, was assessed by a field assessment with the CMAS team and reviewed by the workshop, are illustrated in Figure 3. It is important to note that much of the natural capital is currently overused or infested with alien species and in a poor state.

[4] Henriette, E. et.al. 2017. Enhancing capacity, knowledge and technology support to build climate resilience of vulnerable developing countries. Ecosystem-based Adaptation through South-South Corporation (EbA South). Seychelles Pilot Project Progress Report 7: July - December 2017.

The natural capital discussed above, generates a suite of ecosystem services which are used directly or indirectly by humans. Note that the size and the condition of the assets determine the functionality of the assets and consequently the level of services they can supply. For example, a large intact and highly functional wetland is capable of supplying high levels of water quality maintenance services, sediment capture services and storm surge reduction services. However, if the wetland is fragmented, dried (by drains), reduced in size and invaded by alien species, its functionality will be reduced, and the associated services levels will decline.

The following ecosystem services were identified as being important (by the author) and analysed by the modelling process in the workshop:

- Flood reduction – from upstream catchment
- Storm surge reduction – from the downstream ocean
- Shoreline stabilisation – maintenance of protective coastal vegetation and built infrastructure protection
- Water quality maintenance – the dilution and assimilation of organic and in-organic pollutants, and the reduction of pathogens
- Sedimentation avoidance – within drainage lines and marine outfalls
- Fishing – access to fish, crustacea and molluscs by small scale artisanal fishermen
- Carbon capture and storage - carbon capture by either terrestrial, estuarine or marine habitats
- Nursery (fish and crustacea) and refuge - refuge for fish or crustacea juveniles that naturally replenish commercial fishery stocks
- Food – food plants such as crops and fruit
- Nature appreciation - the provision of areas and habitats for people to appreciate nature such as snorkelling, scuba diving, bird watching, mangrove canoeing, etc
- Recreation - places for recreation such as swimming, walking, hiking, lying on the beach, etc
- Amenity - the provision of visual amenity and sense of place by natural assets such as the clean ocean, white beaches and charismatic granite boulders
- Cultural heritage - space or specific settings provided for the practice of cultural activities, and may include access to areas or features which reinforce cultural beliefs or practices, and add value to communities or society
- Enhancing property values - elevated property prices due to environmental amenities and services
- Conservation of flagship species – contributing to conserving national flagship species (such as turtles and endangered birds)
- National conservation targets - a space to meet national objectives for the conservation of landscapes, or percentages of habitat types conserved
- Ground water recharge - supply of freshwater to ground water for later use or for preventing saltwater intrusion
- Water abstraction – abstraction of water for consumption, such as agriculture or household use
- Transport access – provision of transport access through protection of road infrastructure
- Landslide reduction – slope stabilisation due to dense plant cover and binding roots

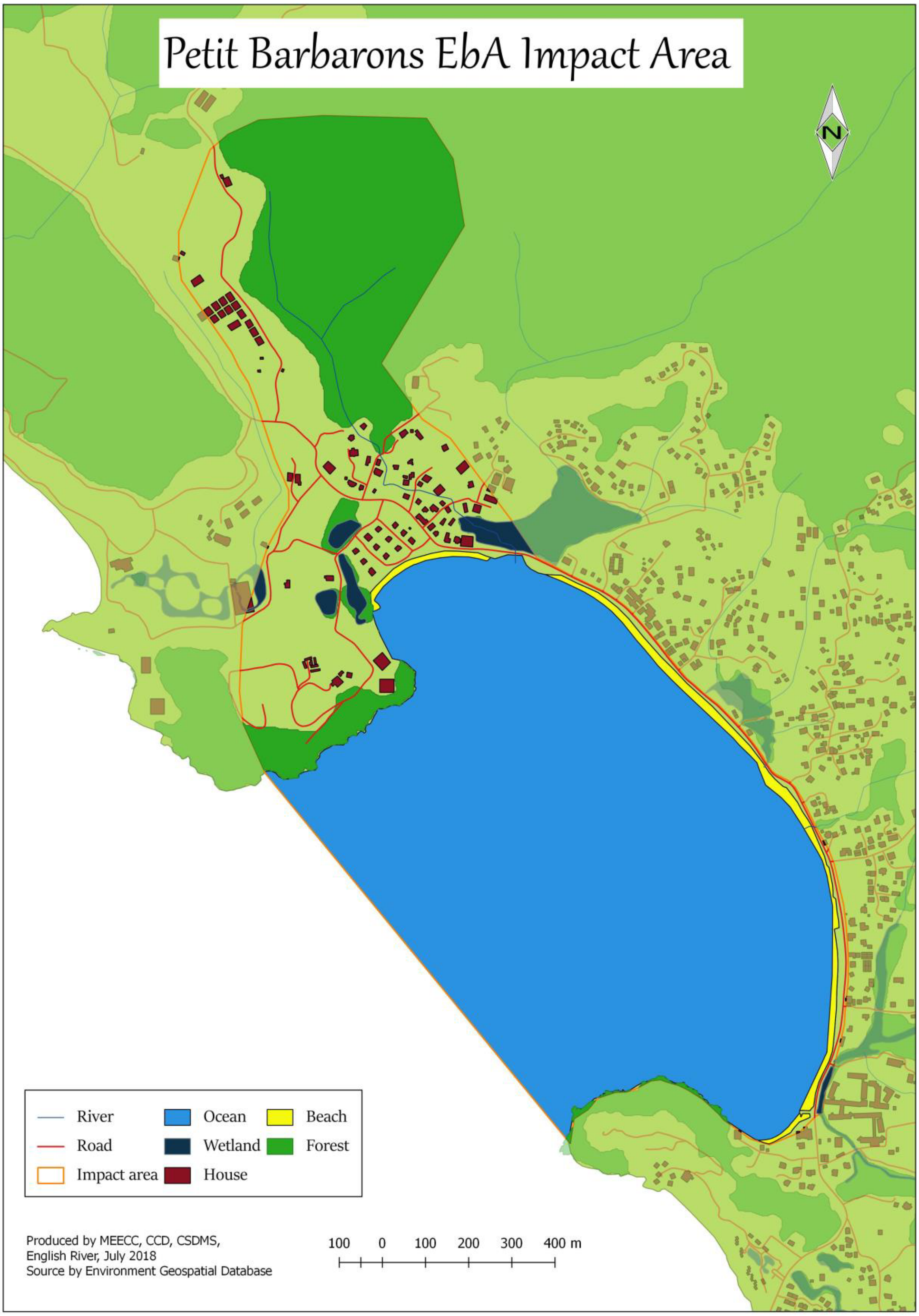

Figure 1: Locality map of the landscape showing boundaries and key land cover types

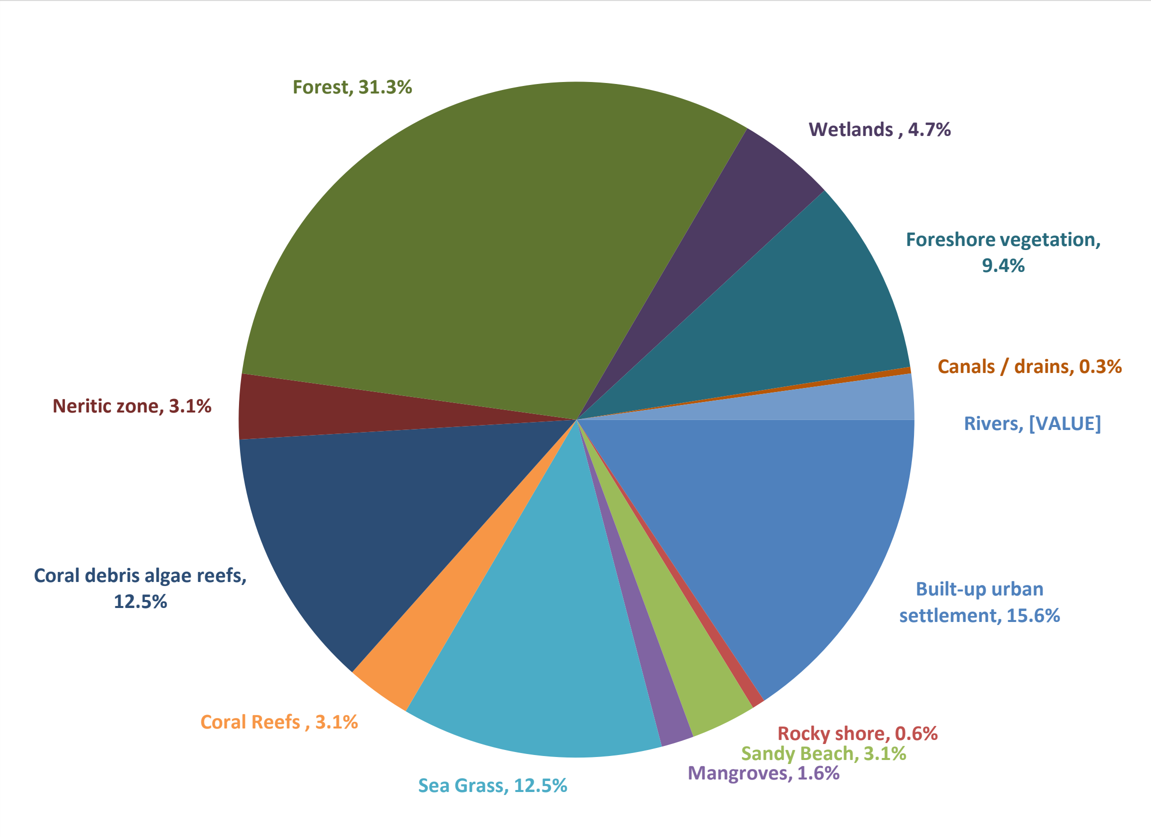

Figure 2: The relative size of the landscape and marine assets

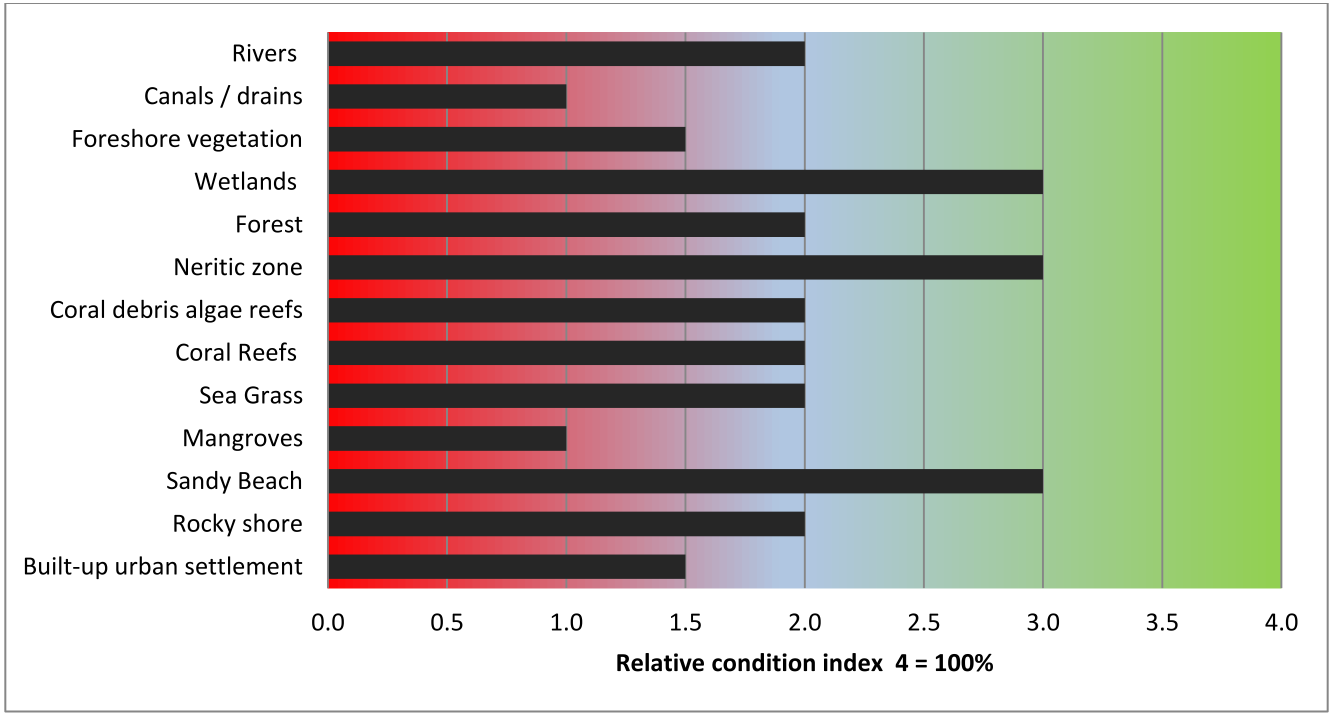

Figure 3: Condition of natural and built assets at Petit Barbarons in 2017 (prior to the intervention)

Implications for climate change adaptation:

- There are a wide range of land cover types or habitats present in the impact area. This implies that interventions in the social-ecological system need to consider impacts on a wide range of ecological processes.
- There are strong hydrological linkages between the different habitat types. For example, in terms of downstream flows, the forests are linked to the coral reefs. The removal of forests will result in accelerated erosion, sediment mobilisation and ultimately discharge to the ocean, where it will generate turbidity and threaten already stressed (due to bleaching) coral organisms. Similarly, septic tank discharge will migrate through the subsoil and be carried by rivers down to the wetlands, mangroves and ultimately discharge to the nearshore zone, once again stressing coral reefs. Similarly, for upstream flows, the development of culverts will enhance more salt water inflow from the ocean and promote mangrove re-establishment. However, this will also imply that the wetlands will be compromised in favour of mangroves, and in turn reduce the wetland's ability to filter downstream migration of pollutants. The implication is that intervening in hydrological systems need to be informed by careful consideration of the direct and indirect impacts of water flows, associated chemical (organic and inorganic) and pathogen flows, and associated sediment flows.

- Many of the habitats were in poor to moderate condition (between 25% and 50% scores). This implies that the social-ecological system is unlikely to be resilient to climate change perturbations, such as storm surges, sea level rise, intense rainfall events and flooding. The condition of the habitats implies that much can be done to promote resilience by improving the condition of the natural capital stock, thereby increasing functionality and elevated services supply.
- There are a wide range of services associated with or produced by the natural capital. This implies that intervening in the system impacts on numerous services and associated service users.

6 THE SUPPLY OF ECOSYSTEM SERVICES AT PETIT BARBARONS

Each of the natural assets or built assets have a unique capacity to supply different ecosystem services. For example, a hardened surface such as rocks or a road surface has no ability to promote water infiltration and consequently cannot reduce floods or promote ground water recharge. On the other hand, a forest has a high capacity to promote infiltration and reduce flooding, but a forest will also lose water through evapotranspiration, limiting ground water recharge. In the modelling process, each habitat may have a zero, low (1 score), low medium (2 score), medium high (3 score) or high capability (4 score) to supply each of the services. See Table 1. These service supply capabilities are considered inherent (and are therefore kept constant in the model) and used together with habitat functionality (which changes), to compute the relative services supply levels or changes in supply. Importantly, as each future scenario alters the functionality of the habitat type, the service levels change in response.

ECOSYSTEM SERVICES	Built-up urban settlement	Rocky shore	Sandy Beach	Mangroves	Sea Grass	Coral Reefs	Coral debris algae reefs	Neritic zone	Forest	Wetlands	Foreshore vegetation	Canals / drains	Rivers
Storm surge reduction	0	4	3	4	1	1	1	0	0	4	3	0	0
Flood reduction (catchment)	1	0	0	0	0	0	0	0	3	0	0	4	0
Shoreline stabilisation (infrastructure protection)	0	3	1	4	1	1	1	0	0	0	4	0	0
Water quality maintenance (dilution and assimilation)	0	0	0	3	3	0	1	4	3	4	3	1	3
Sedimentation avoidance	1	0	0	4	2	0	0	0	4	3	3	1	0
Fishing	0	2	1	4	2	2	1	2	0	0	0	0	1
Carbon capture and storage	0	0	0	3	3	2	0	0	4	3	3	0	0
Nursery (fish and crustacea) and refuge	0	1	1	4	3	3	2	0	0	0	0	0	0
Food (terrestrial)	1	0	0	0	0	0	0	0	1	0	0	0	0
Nature appreciation	0	2	2	4	3	4	2	1	2	1	2	0	2
Recreation	1	1	4	1	1	1	1	1	1	0	1	0	1
Amenity - visual and sense of place	2	4	4	2	0	1	0	2	2	1	2	0	2
Cultural heritage	4	2	2	1	0	0	0	1	2	0	0	0	1
Enhancing property values	3	3	4	1	0	0	0	0	0	0	2	1	2
Conservation of flagship species	0	1	3	2	1	4	1	1	3	1	3	0	1
National conservation targets	0	1	1	4	1	2	1	1	3	4	3	0	1
Ground water recharge	1	0	0	0	0	0	0	0	3	4	1	0	3
Water abstraction	0	0	0	0	0	0	0	0	0	1	0	1	4
Transport access	2	0	0	0	0	0	0	0	0	0	3	3	0
Landslide reduction	0	0	0	0	0	0	0	0	4	1	0	1	1

Table 1: Ecosystem service supply capability by habitats in pristine condition (score range from 0 (red) to 4 (dark green)

By combining the capability scores with ecosystem functionality (that is, the product of the scores), it is possible to indicate the relative contribution of each habitat type to the supply of discrete services. Figure 4 illustrates the relative contribution of each habitat type to the supply of a service in terms of its current state and size. For example, in terms of flood reduction services, drains and forests are the two dominant suppliers, with forests contributing some 98% of the flood reduction service. Consequently, any changes to the upstream forest will have large scale impacts on flood reduction services. On the other hand, if the desire is to enhance property values, then the adjacent sandy beach quality and size, and the foreshore vegetation quality and size, are going to play critical roles. The beach asset will make the property attractive to holiday home buyers, and the foreshore vegetation will secure the protecting foredune and prevent erosion of the property by the ocean. Note that the forests dominate service supply and any reduction of forests are likely to reduce resilience to climate change, especially considering landslides risks, water security risks, visual amenity and water quality maintenance. Conversely, any increase in forest condition or size, will generate greater resilience as service levels increase.

Note transport access service supply is dominated by foreshore vegetation as much of the connecting road networks are immediately adjacent to the beaches, and any loss of foreshore vegetation will have dramatic negative impacts on transport access.

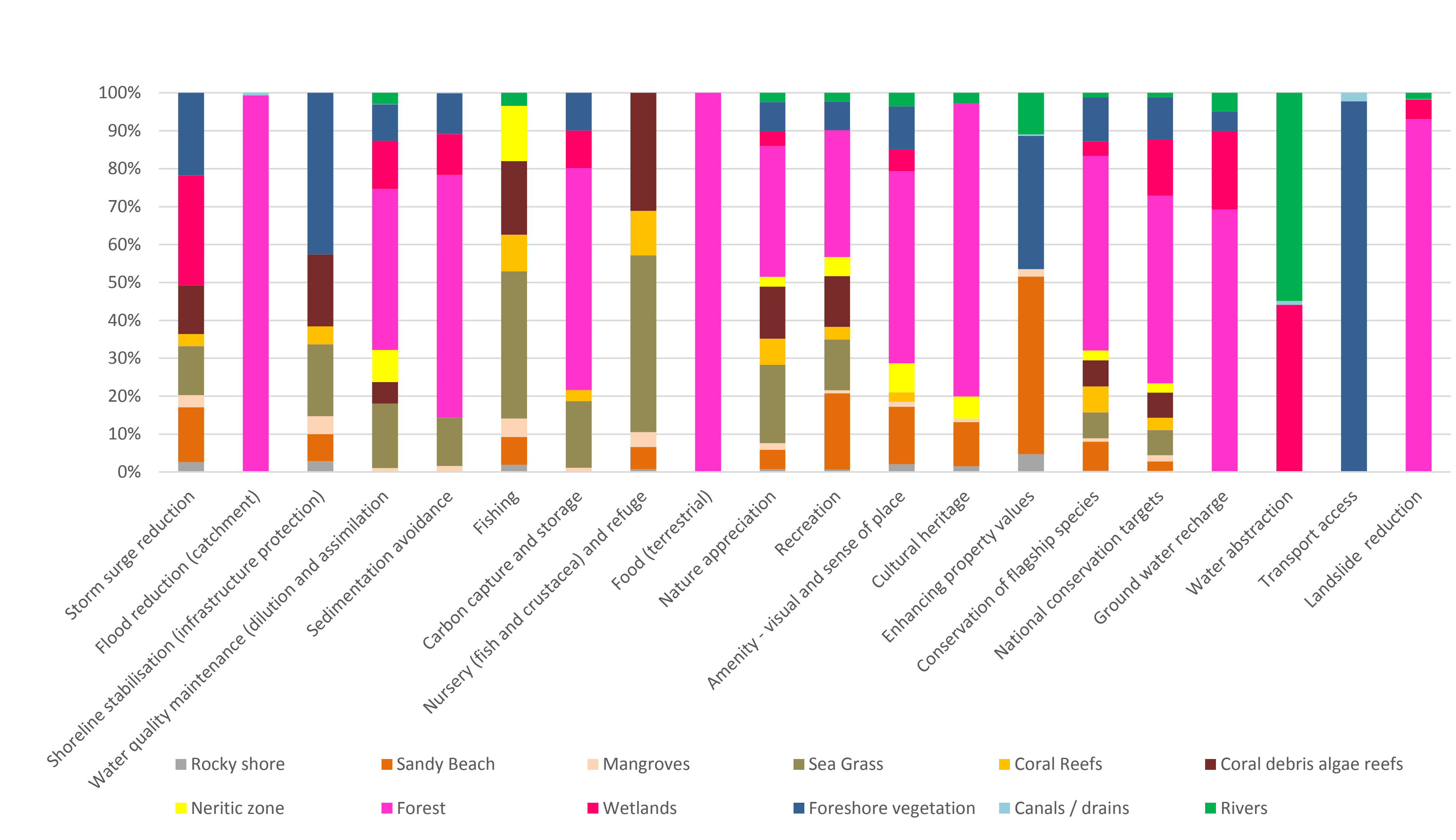

Figure 4: The relative contribution of discrete ecosystem services per habitat type

Figure 5 shows the range and relative levels of services supplied by each of the land cover types for 2017, prior to the EbA interventions, and constitutes the baseline situation which is used to analyse future scenarios. The relative levels are a product of functionality (a weighted score of area and condition) and service supply capabilities (an inherent capability in pristine conditions). Importantly, the service levels shown are an index relative to other each other, showing relative abundance and scarcity. Services clustered on the left are relatively abundant (such as water quality maintenance and carbon capture), while service on the right are relatively scarce (such as water abstraction, transport access and food).

The implications for climate change adaptation:

- The natural capital at Petit Barbarons can play an important role in mitigating the impacts of climate change in Seychellois society, and include:
    - *Protecting* built infrastructure and property values by preventing flooding, storm surge, landslides, coastal erosion and the loss of transport access. Note that these services are supplied at relatively moderate to low levels and are therefore going to grow in value as climate change manifests itself further in the Mahé.
    - *Enhancing* built infrastructure values by providing amenity, sense of place and recreation opportunities. Note that these services are supplied at relatively high to moderate levels, and hence one sees a strong international demand for Mahé as a property investment and holiday destination. However, amenity and recreation services are supplied by many habitat types and implies that all the assets need to be secured by environmental management for Mahé to continue to be a global tourist destination. Climate change is likely to impact the beaches, foreshore vegetation and coastal infrastructure, all of which are critical for securing tourism. This implies climate change adaptation responses will need to focus on securing these assets.
    - The natural capital is capable of supplying a safe and healthy environment for residents and visitors to live in by assimilating human waste and promoting good water quality, with fewer pollutants and pathogens. This service is supplied at relatively high levels. However, climate change can reduce functionality and reduce these service levels, with elevated runoff and flooding, and the loss of wetland filtres.
    - Promoting resilient economic activities, such as tourism and fishing, by supplying elevated recreation services, fish nurseries and fisheries. These services are supplied at a wide range of levels. Again, climate change can reduce these service levels and a special focus needs to be made to increase all these services so that they are more resilient to changes.
    - Promoting conservation of Seychellois biodiversity by promoting resilient ecological systems. These services are supplied at relatively high levels but are vulnerable to climate change.
- While climate change has the potential to degrade ecosystems and reduce service levels, it is largely the ongoing conversion of natural capital, over-use (harvesting) of ecosystems, increasing pollution discharge, infestation by alien species and water flow disruptions (alien plant evapotranspiration, accelerated runoff, abstraction and diversion) which are currently running down the terrestrial and marine natural capital. The implication is that systemic environmental management is required to reverse current trends and to maintain or enhance natural assets to the point where they are capable to playing a decisive role in climate change mitigation. The failure to reverse current trends will imply that climate change impacts are compounded by current environment management levels. This implies abundant natural capital services will need to be replaced by built capital services, using scarce financial capital. It is unlikely that this will be affordable, and maintenance of existing ecological infrastructure will by far be the cheapest option facing Seychellois society.

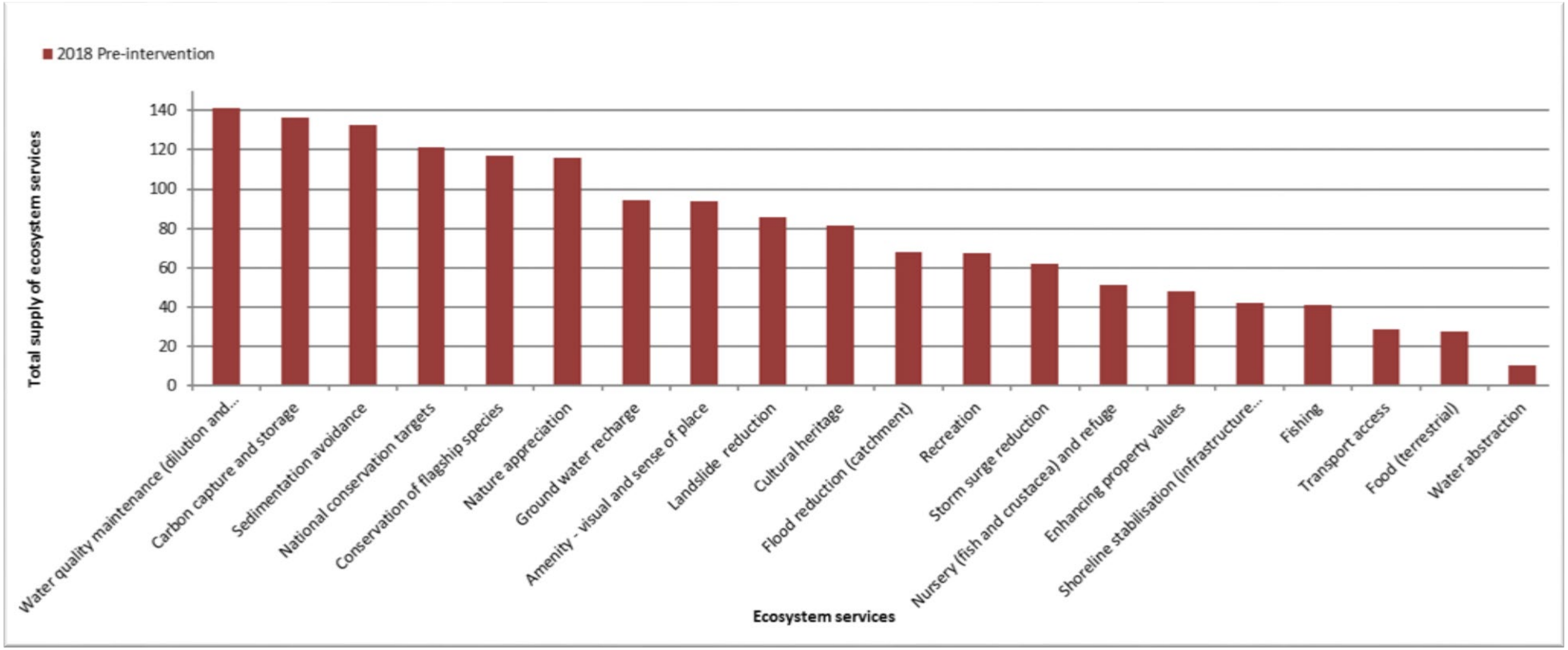

Figure 5: Graph showing the 2017 relative levels of ecosystem services supplied by each land cover type

7 THE DEMAND FOR AND BENEFITS OF PETIT BARBARONS ECOSYSTEM SERVICES

The above discussion on ecosystem services supplied and their relative levels needs to be seen in the context of the demand for ecosystem services. For example, if a service is relatively abundant and declines due to functionality changes, but there is little demand for the service, then there are minor implications for Seychellois society. On the other hand, if a service is relatively scarce, and service levels decline in conjunction with a high demand for the service, then there are likely to be major implications for Seychellois society. An analysis of ecosystem services' demand helps to identify priorities for interventions.

Table 2 outlines the demand and benefits for each of the ecosystem services. The total number of beneficiaries were estimated by the workshop, based on local observations and available estimates. Note that the beneficiaries may be comprised of different levels of dependence, with some users having a critical dependence (or lifesaving /life changing impact), high dependence (important service used regularly), moderate dependence (a service used to a moderate level) and a low dependence (a service used a few days a year – such as foreign tourists). Note that the red numbers below the headings, indicate the weighting used. The Human Benefit Index[5] combines different users of different intensity and frequency of use, to create a single weighted benefit score, that permits comparisons between services (Figure 6) or between different scenarios. In simple language one could conceptualise the Human Benefit Index as the number of fulltime users highly dependent on the service (made up of 'full-time' and 'part-time' users of variable dependence).

The estimated Human Benefit Index shows the benefits supplied between the different ecosystem services. Table 2 and Figure 6 shows which services have the greatest benefit to society compared to the lowest benefit levels. It also shows which services have critical, high, medium and low dependence scores. For example:

- Ground water recharge has the lowest or no score, as there are no users of ground water at Petit Barbarons.
- The flood reduction service has some 150 beneficiaries, of which 1% have a critical dependence, 50% a high dependence, and 49% a moderate dependence. There are differences in dependence as some households are on relatively higher ground and will have less frequent floods. The weighted score is 57 (fulltime human equivalents).
- The recreation and amenity services have a high score of 9 720, as there are estimated to be 90 000 users of these services in a year. However, only 20% have a high dependence (the estimated number of Seychellois people associated with the tourism in this part of Mahé) and 80% have a low dependence, which are the foreign tourists who have other destinations to choose for holidays and would not suffer greatly by not coming to Petit Barbarons.
- Transport access services have the highest level of critical users, and any disruption of transport access due to sea level rise or flooding, will have serious impacts for enterprises, commuting workers and access to social services (such as schools).

[5] Cartwright, A., Blignaut, J., De Wit, M., Goldberg, K., Mander, M., O'Donoghue, S. and Roberts, D. 2013. Economics of climate change adaptation at the local scale under conditions of uncertainty and resource constraints: the case of Durban, South Africa. Environment and Urbanization. https://doi.org/10.1177%2F0956247813477814

The different human benefit indices highlight the need to consider the full range of services when selecting climate change responses. For example, while the constructed drains and channels have increased the flood reduction services in the short term to 57 fulltime human equivalents, it has also reduced water quality maintenance services for 363 fulltime human equivalents. To optimise the net social gain, it is critical to consider all the key service changes and its impact on all their associated users.

	Total number of beneficiaries	% Critical dependence	% High dependence	% Moderate dependence	% Low dependence	Weighted benefit score
ECOSYSTEM SERVICES		1	0.5	0.25	0.01	Human Benefit Index
Storm surge reduction	150	0%	50%	50%	0%	56
Flood reduction (catchment)	150	1%	50%	49%	0%	57
Shoreline stabilisation (infrastructure protection)	40	1%	33%	33%	33%	10
Water quality maintenance (dilution and assimilation	2 000	1%	33%	0%	66%	363
Sedimentation avoidance	20	1%	50%	49%	0%	8
Fishing	200	0%	80%	20%	0%	90
Carbon capture and storage	96 000	0%	0%	1%	99%	1 190
Nursery (fish and crustacea) and refuge	600	0%	10%	20%	70%	64
Food (terrestrial)	150	1%	10%	30%	69%	21
Nature appreciation	60 000	0%	20%	0%	80%	6 480
Recreation	90 000	0%	20%	0%	80%	9 720
Amenity - visual and sense of place	90 000	0%	20%	0%	80%	9 720
Cultural heritage	1 920	0%	33%	33%	34%	482
Enhancing property values	300	0%	100%	0%	0%	150
Conservation of flagship species	96 000	0%	0.5%	1.5%	98%	1 541
National conservation targets	96 000	0%	0.5%	1.5%	98%	1 541
Ground water recharge	0	10%	90%	0%	0%	-
Water abstraction	75	0%	30%	70%	0%	24
Transport access	9 600	1%	45%	54%	0%	3 552
Landslide reduction	150	20%	80%	0%	0%	90

Table 2: The demand for ecosystem services and their associated Human Benefit Index (red shading denotes highest human benefit while the green denotes the lowest benefit levels)

Implications for climate change adaptation:

- The Petit Barbarons area offers multiple benefits to multiple user groups, using an integrated social-ecological system, where no habitat or living natural asset is independent of others. Consequently, climate change interventions should consider changes to all service benefits, in order to optimise human wellbeing in Mahé.

- Focussing an intervention on a single user group, such as flood reduction users, is likely to produce suboptimal outcomes in terms of human wellbeing and economic benefits.
- Prior to intervening, the Seychelles Government should identify which response will offer the greatest net benefit to society. In other words, which action will offer the greatest level of benefits per Rupee spent. This implies not doing a partial analysis, but a more comprehensive analysis that considers the costs and benefits to all service user groups.

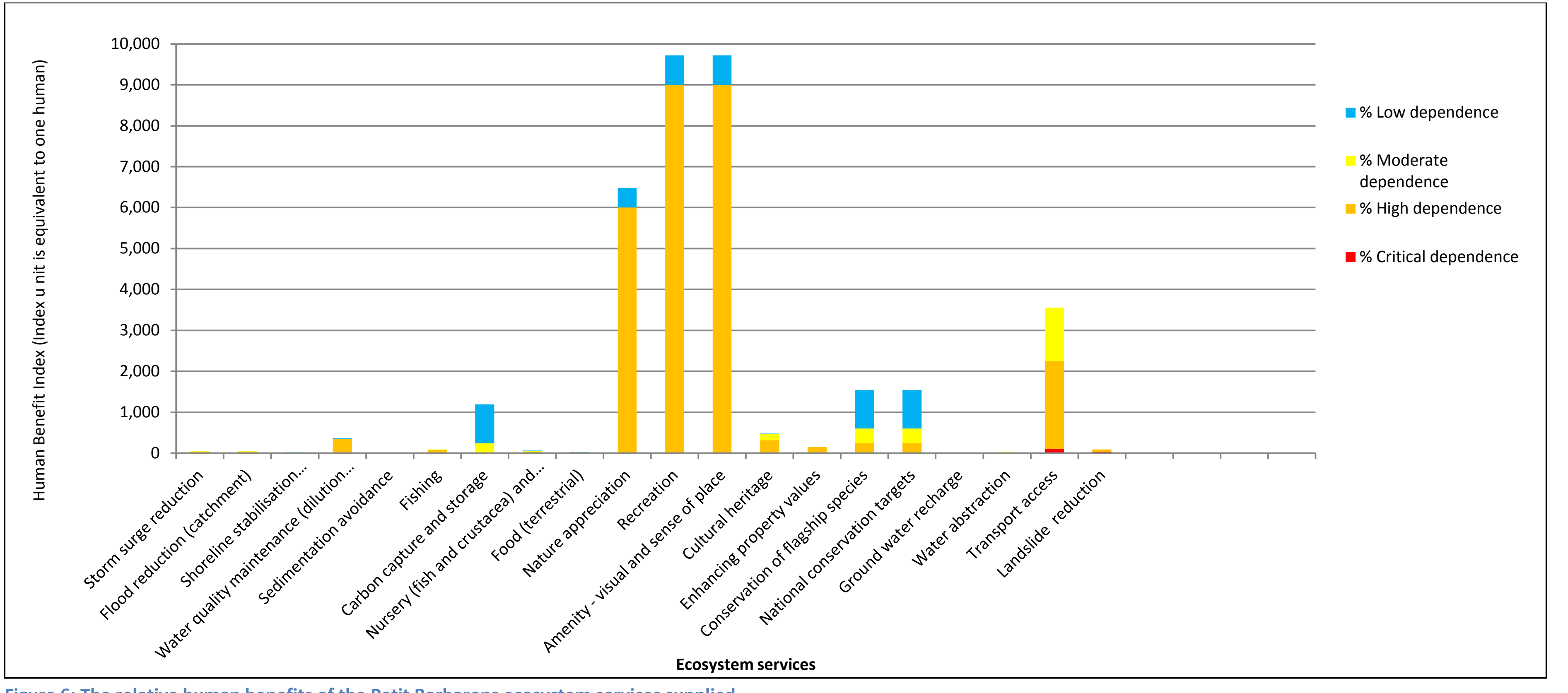

Figure 6: The relative human benefits of the Petit Barbarons ecosystem services supplied

8 THE ECOSYSTEM-BASED ADAPTATION SCENARIOS FOR PETIT BARBARONS

To better understand the benefits of ecosystem-based adaptation responses to climate change, it is necessary to develop a range of scenarios. The scenarios used are outlined below. Table 3 shows the changes in the composition (which habitat type), changes in size (estimated in hectares) and changes in condition (in terms of a four-point score, with score 1 = 25% of pristine condition, score 2 = 50% of pristine condition, score 3 = 75% of pristine condition and score 4 = 100% of pristine condition) of natural and built capital associated with each scenario. These changes were discussed extensively and agreed on in the Climate Adaptation & Management Section workshop and the reasoning is not documented in this report. The consequences of changing the composition, size and condition of natural and built capital, are changes in the ecosystem services' supply levels. The resulting service level changes, computed by the Ecofutures model, are illustrated in Figure 7 and Figure 8.

The climate change scenarios modelled are as follows:

- **2018 Pre-intervention** – is the baseline scenario or yardstick to build the future scenarios. This scenario reflects the situation prior to the introduction of the drains, channels and mangrove restoration. In the radar graphs below, the red line denotes the status quo in terms of the service supply level when all services are normalised to 100%. Any changes in service levels in other scenarios are then reflected as either above or below 100% supply levels (red line).
- **2018 Intervention only** – only the direct impact of the intervention is considered with no ecological consequences or accounting for future climate change. This is an unrealistic scenario and only used to illustrate the danger of not accounting for systemic changes when planning interventions. Note that in this scenario, the intended purpose of the intervention, that is flood avoidance, is well achieved with the addition of elevated property values and elevated access to transport. If all variables are kept constant, then the desired services are achieved. See Figure 7. However, this scenario is not plausible, as it does not account for settlement growth, rising pollution levels, increasing alien plant invasions or future climate changes, and is therefore not useful for decision making. For example, as settlement increases there will be additional accelerated run-off, generating additional water volumes, thereby reducing the effectiveness of the flood reduction drains. In addition, water quality declines due to the reduction of wetland functions and elevated human settlement, all leading to a decline in water quality in the near shore zone. Furthermore, with increased tidal flows through the culverts, there will be greater landward flows of sea water, and this is further exacerbated the deterioration of the wetlands, leading to greater risk of storm surge. These consequences need to be accounted for, and hence the need for more plausible systemic scenarios.
- **2028 Without the Intervention** – to understand the magnitude of benefits which EbA may generate, it is necessary to determine the difference between a future 'with' and 'without' intervention environment. Consequently, the impacts of climate change in the Seychelles need to be built into all the future scenarios. In this scenario, it assumes no intervention takes place, but climate change occurs, natural resources continue to be highly utilised, non-point source pollution grows, population grows marginally, and settlements grow at the expense of forest areas. The consequences of these changes are a reduction in most of the ecosystem service levels. Figure 8 shows that there could be contraction in services of between 20% to 30%. This implies more people and fewer services, with a decline in services per capita in other words, a decline in Seychellois wellbeing. Much of the decline is due to a combination of both increased human pressure and climate change.
- **2028 With Intervention** – in this scenario, the interventions (drains, canalised wetlands, mangrove restoration and shoreline vegetation restoration) are applied to the 2028 No Intervention scenario. This scenario accounts for climate change, population growth, settlement growth, reduced forest and ecological knock-on effects. It sees a growth in mangroves (size and condition) in response to increased tidal inflows and restoration, but also results in reduced wetlands

(size and condition) in response to canals, salt water intrusion and fragmentation. In this scenario water quality declines as a result of increased settlement, and these impacts are transferred downstream to the ocean habitats, as the wetland filtration functions are compromised. In this scenario, transport access, property price maintenance and shoreline stabilisation increase above current levels – as intended. Transport access and shoreline stabilisation are largely a function of the restoration work and elevated mangrove condition. Property values rise due to additional new buildings being established in the area. However, many of the other ecosystem services are likely to be below current service levels. The implications of this scenario are that the current interventions are unlikely to be adequate in 10 years' time, and that changes to wetland functionality have negative impacts on the receiving ocean habitats. Consequently, one needs to consider alternative or additional options to deal with declining service per capita.

  - Note: this scenario consists of both engineered actions (culverts, drains and cut channels) and ecosystem-based actions (alien plant clearing and mangrove restoration). However, the response is dominated by the engineering works to accelerate floodwater flows out of the residential area using culverts, drains and channelled wetlands. These flow changes dominate the ecological and social impacts and this scenario is strongly influenced by engineered works. The culverts will promote mangrove growth with greater tidal flows, but this action will not promote rainwater flood reduction, as the mangroves are between the houses and the ocean, and if anything could slow flood water down, and promote back-flooding. Note that storm surge flooding (from the ocean) will be reduced by the mangroves but accelerated by the engineered works. In Petit Barbarons it is not possible to mitigate rainwater flooding and storm surge flooding by the same interventions. There is a clear trade-off between the two.

- **2028 Catchment Management and Drains** – this scenario is similar to the 2028 With Intervention scenario, except for the inclusion of upstream catchment management. To address the loss of wetland functionality and services, one option is to enhance the functionality of upstream forests, rivers and settlements, thereby reducing flood waters and limiting poor quality water arriving at the compromised wetlands, and thus reducing the negative ocean impacts of poor water quality. The implications of this scenario is that to accommodate the increased human pressure on the system in a changing climate, catchment management would need to be included in a response strategy in order to create a net positive impact. To reduce long term flooding and poor water quality to above present levels, the catchment needs to be managed, and this includes managing both green infrastructure (nature) and built assets. As noted in Section 6, without systematic environment management in the catchment and coast, climate change will compound welfare loss or economic costs. Furthermore, single site-specific interventions, such as drains, are unlikely to promote long term resilience. Conversely, environment management together with site-specific interventions, is likely to promote a resilient Mahé society.
  - Note: this scenario could be considered as a hybrid option, as it combines the previous largely engineered works, with a substantial ecosystem-based adaptation, that is, catchment management (which includes forest management, managing residential properties (storm flow and pollution), coastal vegetation restoration (mangroves and fringing vegetation), *but* leaving the wetlands channelled for floodwater removal). This scenario was created to offset the negative elements of the engineered response (the channelling of wetlands).
- **2028 Intervention but No Maintenance** – in this scenario, similar to 2028 With Intervention, but no maintenance of the interventions takes place. The mangroves and foreshore vegetation are not maintained and allowed to become degraded. The benefits of this scenario are generally lower than the 2028 No intervention scenario, largely as a result of the compromised wetlands. However, it is possible that the wetlands may improve if not canalised again, but the effects of saltwater intrusion may negate these gains. The implications of this scenario is that maintenance is required to ensure that the intervention does not a generate net cost or loss to Mahé society.

ECOLOGICAL ASSETS	Built-up urban settlement	Rocky shore	Sandy Beach	Mangroves	Sea Grass	Coral Reefs	Coral debris algae reefs	Neritic zone	Forest	Wetlands	Foreshore vegetation	Canals / drains	Rivers
2018 Pre-intervention													
CONDITION - score relative to its potential - 4 to 0	1.50	2.00	3.00	1.00	2.00	2.00	2.00	3.00	2.00	3.00	1.50	1.00	2.00
SIZE - area in ha	5.0	0.2	1.0	0.5	4.0	1.0	4.0	1.0	10.0	1.5	3.0	0.1	0.7
2028 Without intervention													
CONDITION - score relative to its potential	1.00	2.00	3.00	1.00	2.00	1.50	2.00	3.00	1.50	3.00	1.00	0.50	1.50
SIZE - area in ha	7.0	0.2	0.7	0.5	4.0	0.5	5.2	1.0	8.0	1.5	2.7	0.1	0.7
2028 With intervention													
CONDITION - score relative to its potential	2.00	2.00	2.50	2.50	1.50	1.00	1.50	3.00	1.50	2.00	2.00	4.00	1.50
SIZE - area in ha	6.5	0.2	0.7	1.0	4.0	0.0	5.7	1.0	8.0	1.0	2.7	0.6	0.7
2028 Catchment Management + Drains													
CONDITION - score relative to its potential	3.00	2.00	3.00	3.00	2.00	1.50	2.00	3.00	3.00	2.50	2.00	4.00	2.50
SIZE - area in ha	6.50	0.20	0.67	1.00	4.00	0.50	5.16	1.00	8.00	1.00	2.67	0.60	0.70
2028 Intervention but no maintenance													
CONDITION - score relative to its potential	1.50	2.00	2.50	2.00	1.50	1.00	1.50	2.50	1.50	2.00	1.00	1.00	1.50
SIZE - area in ha	6.5	0.2	0.7	1.0	4.0	0.0	5.7	1.0	8.0	1.0	2.7	0.6	0.7
2018 Intervention only													
CONDITION - score relative to its potential	2.00	2.00	2.50	2.50	1.50	1.00	1.50	3.00	2.00	2.00	2.00	4.00	2.00
SIZE - area in ha	4.5	0.2	0.7	1.0	4.0	0.0	5.7	1.0	10.0	1.0	2.7	0.6	0.7

Table 3: Changes to the size and condition of habitat types in different scenarios

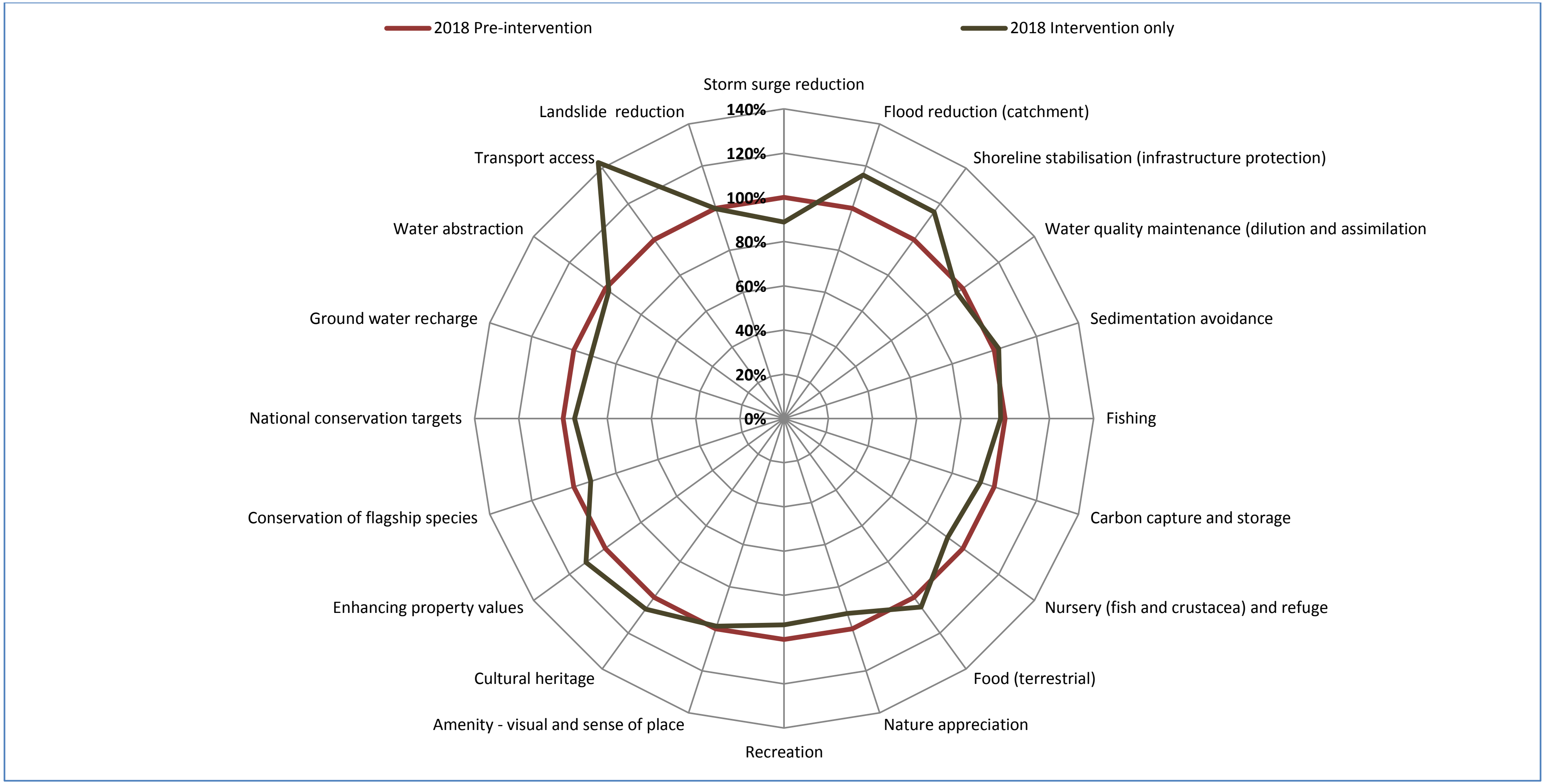

Figure 7: Changes in the ecosystem services in the unrealistic 2018 Intervention Only scenario (the red line is the current level - with all services normalised to 100%)

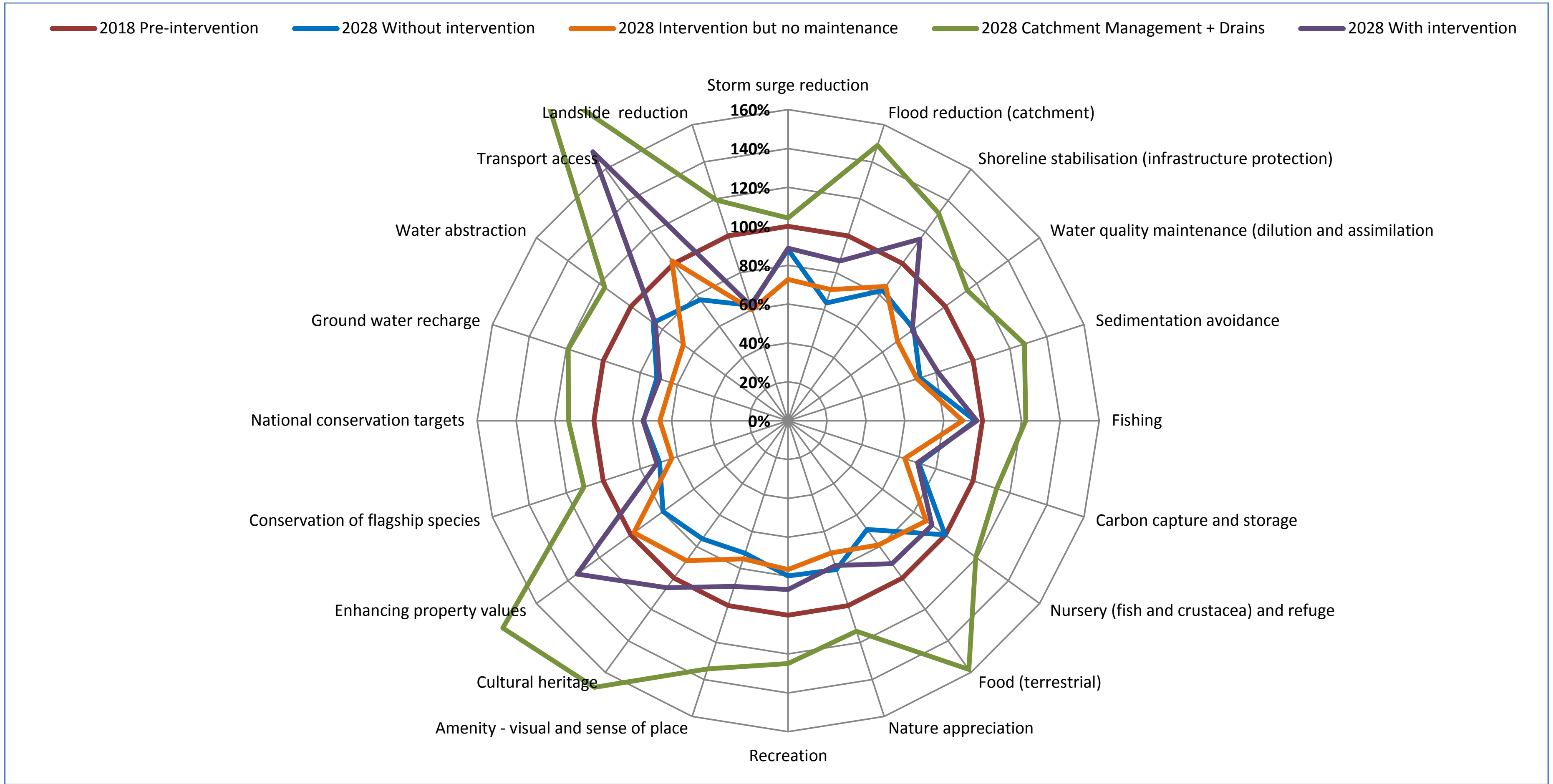

Figure 8: Changes in the ecosystem services in possible adaptation scenario (the red line is the current level - with all services normalised to 100%)

9 THE IMPACT OF CLIMATE CHANGE RESPONSES TO SOCIETAL RISKS

A driver of climate change adaption is to reduce the risks of climate change to society. In the Seychelles, the key risks are[6]:

- sea level rise
- salination of ground water due to salt water intrusion
- greater intensity rainfall events
- greater frequency of landslides
- a decline in water abstraction associated with drier periods
- coral bleaching

In this analysis, the risk to ecosystem services in different scenarios is shown by a risk index, where Risk Index = demand/supply[7]. The risk associated with each ecosystem service in each scenario is illustrated in Figure 9. The services at greatest risk are recreation, transport access, amenity and nature appreciation. The impacts of the climate change responses to risk are outlined below:

- Recreation – the risk to recreation is elevated with climate change and may not be significantly reduced by the current interventions. In addition, without maintenance, the current intervention could increase risk above a No Intervention scenario. In other words, society may be at greater risk than before if the interventions implemented are not managed. However, a further investment in catchment management could significantly reduce risk levels, to even below current level, despite future climate change, population growth and settlement growth. The risk to recreation could limit future tourism amenity and investment in this precinct, and similarly for other vulnerable locations in Mahé.
- Nature appreciation and visual amenity /sense of place – the risks and their trends associated with visual amenity and nature appreciation are similar to recreation risk above, but of a lower magnitude.
- Transport access – the risk to transport access is elevated by climate change, however the current intervention can reduce this risk substantially. While the EbA intervention was planned to reduce the risk to homestead flooding, the impact on reducing transport access risk is much more significant. This is due to there being far greater numbers of road users than affected home owners and fewer buffers for road protection.
- The implication for climate change adaptation is that the current intervention is:
  - Able to significantly reduce transport access risk, but
  - Does not reduce risk for recreation, nature appreciation and amenity – which are some of the critical services underpinning the Mahé tourism economy.
  - The current intervention is necessary but not sufficient to secure the economic drivers.
- Consequently, catchment management is a necessary addition to the current interventions, to ensure a resilient environment able to sustain social well-being and the economy on the Mahé south west coast.

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[6] Government of Seychelles. 2013. Seychelles Damage, Loss and Needs Assessment (DaLA). 2013 Floods.
Massey, S. and Schumtz, M. 2017. Water catchment areas in the Seychelles: Vegetation quality and human impact analysis and evaluation. Department Environmental Systems Sciences. Swiss Federal Institute of Technology.

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[7] Risk is a function of a combination of the demand and supply levels. In this analysis, the formula [Risk = Human Benefit Index / service supply index] is used, or in other words, how many demand units are there for each service supply unit available. Both the human benefit index and service supply index are computed in this analysis.

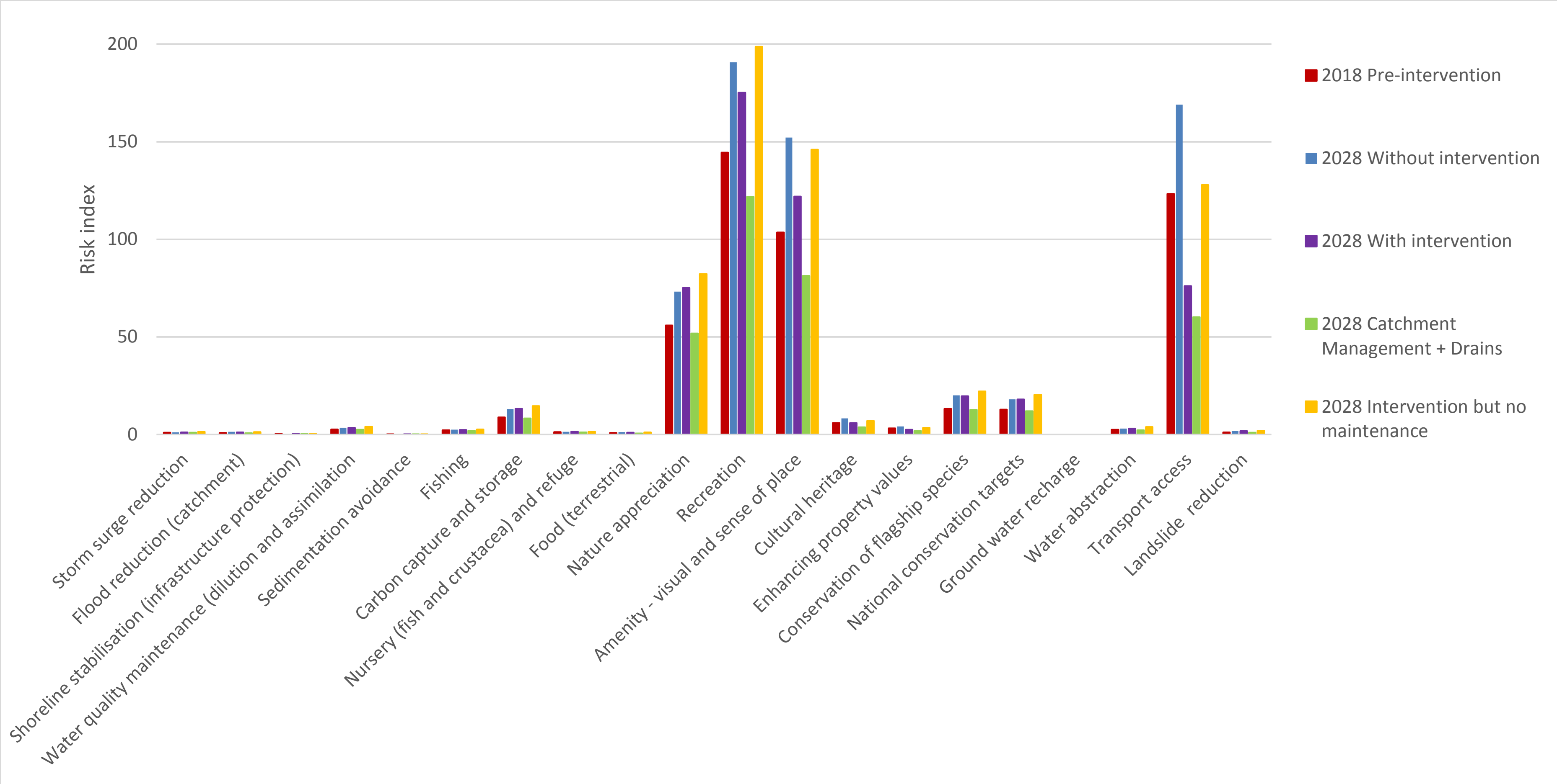

Figure 9: Changes in the relative risk levels in the adaptation scenarios

10 The costs and benefits of climate change interventions

The cost benefit analysis did not have resources to undertake any primary research, and consequently focused on using currently available information. As the intervention costs were the most reliable data available, these costs where used as the baseline and the benefits were calculated as a unit of cost. The term 'benefit cost analysis' or BCA is therefore used in this analysis.

Two analyses were undertaken to inform decision making.

- In the first BCA, the intervention costs (in monetary terms) are compared to potential benefits supplied (also in monetary terms). However, in this analysis the monetary benefit values are the currently available published estimates of ecosystem values, calculated for other localities around the globe. The usefulness of the global estimates is that they provide an 'orders-of-magnitude' indicator of ecosystems' worth, for decision makers to consider. These benefits are however weak indicators of Seychellois' reality as they do not account for locally specific factors, such as the number of users and intensity of ecosystem service use by residents.
- To account for local service demands, a second analysis was undertaken, which compared the monetary intervention costs to the Human Benefit Index. In other words, how much human benefit is generated by US$1 spent. In this analysis, the Human Benefit Index is used to show the benefits in terms of the numbers of service users and intensity of service use, resulting from the intervention. Even though an index is used, this analysis is a good indicator of the level of benefit supplied as it correlates to locally specific wellbeing or the local level of consumption of services. The human benefit index is the index calculated by the Ecosystem Services workshop with the Seychellois team (see chapter 7). This BCA estimate should be a key focus of decision making as it uses the local reality to determine benefit levels.

10.1 The parameters and model used

An Excel spreadsheet was developed to calculate the two benefit cost values and ratios for different climate change response scenarios. An Excel spreadsheet model is supplied with this report and can be used for further analysis or can be adapted for application in other sites. The detailed workings of the spreadsheet are not described in this report but are annotated or evident in the spreadsheet. The following parameters are built into the BCA model:

- Five climate change response scenarios have been modelled.
- Duration of the intervention. A 30-year timeframe has been used in the analysis but can be altered as required.
- The social discount rate – two options are provided, a pessimistic outlook (using 15%) or an optimistic outlook (using 6%). This analysis has used an optimistic outlook to discount the future values.
- A management effectiveness factor – again two options are provided. An effective management outlook (using an assumed 75% of published benefit values) or an ineffective management outlook (using an assumed 50% of published benefit values). This analysis has used an effective management outlook.
- Six interventions were modelled, including drains, culverts between wetlands, channels in wetlands, mangrove restoration, fringing vegetation restoration, and alien plant clearing on upstream mountain slopes.

- The costs of each intervention are captured in terms of capital costs (including future repair costs and frequency of future repairs) and annual operating costs. These costs have been provided by the EbA South project and Government of Seychelles. The frequency of recurring events such as flooding, is assumed to be 10 years (CAMS estimate and corroborated with http://thinkhazard.org/en/report/220-seychelles/CF)(and can be altered if required). For the scenarios where no interventions are undertaken, an opportunity cost has been estimated to reflect current flood damage costs. In this analysis the opportunity cost (of flood damage) is assumed to be 10% of the affected property values (accounting for damage to house and house contents). There are currently 13 houses in the immediate vicinity of the affected site and this is estimated to increase to 18 in the future (as per % change estimated in the workshop).
- The present value of interventions or opportunity costs have been calculated using monetary costs, time and the social discount rate.
- The functionality of ecosystems. This factor (the product of habitat size in ha and habitat condition) was calculated in the Ecosystem Services workshop and has been used to determine the changes to the levels of services generated by different habitats in different scenarios. This is to identify priority habitat types for management. The three top suppliers (habitats) for each ecosystem service were used to calculate the service level changes.
- The changes in ecosystem service supply levels (as a %) in each scenario is assumed to reduce the human benefit index by the same percentage. This may not always reflect reality but is used as a 'best available proxy' in the absence of scientifically proven relationships for each service at Petit Barbarons.
- The monetary benefit values are derived from both De Groot 2012[8] and Blignaut et al 2016[9]. Where the affected site habitat correlated directly with those in published literature, such as sea grass, the exact value per hectare was transferred. However, for habitats, such as drains, a fraction of a similar habitat was used. For example, 10% of river value was used to value drains. The Petit Barbarons value was estimated by multiplying the published value per hectare with the area (number of ha) of affected habitat at Petit Barbarons, and also included a management effectiveness factor.

10.2 The benefit cost model outcomes

The BCA model outcomes are outlined in Table 4 below. It is important to focus on the 2028 Without Intervention scenario, as this it the likely future with climate change and no intervention. It is the 'do nothing' scenario and consequently an appropriate baseline for comparing interventions.

[8] De Groot, R., Brander, L., Van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., Ten Brink, P., Van Beukering, P. 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services, 1:50–61.

[9] Blignaut, J. Mander, M, Inglesi-Lotz, R., Claire-Glavan, J and Parr, S. 2017. Economic value of the Abu Dhabi coastal and marine ecosystem services: Estimate and management implications. In Azar, E. and Raouf, M. (Eds.) *Sustainability in the Gulf*. Routledge. (https://www.routledge.com/Sustainability-in-the-Gulf-Challenges-and-Opportunities/Azar-Raouf/p/book/9781138040687)

In terms of the BCA combining intervention and opportunity costs with published ecosystem value, the following should be noted:

- The present value of potential benefits flowing from Petit Barbarons ecosystems shows that in the 2018 Pre-intervention scenario, the benefits could be worth some US6.3 million and could decline to US5.6 million without interventions. Note that these benefits do not reflect local demand and should not be used for decision making, but do serve to show the likely magnitude of service values.
- The intervention and opportunity costs of the scenarios show that 2028 Without intervention has the highest costs. The highest costs are likely to be incurred by doing nothing. It is noteworthy that the 2028 Catchment Management and Drains scenario has the least costs despite incurring more intervention costs. This is due to the greater reduction in recurring damage costs, as the upstream catchment improves. Note that this scenario also has less costs than a no-maintenance scenario, implying that not spending on maintenance is false economy.
- The benefit cost ratios using the published ecosystem values should **not** be used for decision making given their lack of local context.

In terms of the BCA combining intervention and opportunity costs with the Human Benefit Index, the following should be noted:

- The same costs are used in this analysis as the previous analysis, but uses a human benefit index as a proxy for benefit values. The Human Benefit Index reflects the local level, intensity and importance of service use, and therefore is a more realistic reflection of benefits and BC ratio.
- The **Human Benefit Index** (or simply the magnitude of benefits) is greatest for the 2028 Catchment Management and Drains scenario, or 141% of the pre-intervention scenario. This implies that this intervention will reverse the losses as a result of climate change, and in addition offset the wetland losses resulting from wetland channelling. Without an intervention, the human benefits associated with the Petit Barbarons area (terrestrial and marine) is likely to decline by some 19%. The 2028 With Intervention scenario indicates that the human benefits could be 17% more than a no-intervention scenario, but still similar to the pre-intervention scenario. In other words, the current intervention will keep well-being levels at current levels despite flooding costs reduction, climate change losses and wetland functionality losses. This implies that the benefits may shift between users, towards flooded households and away marine user households (affected by wetland losses and climate change).
- The BC ratio if expressed using 2018 Pre-intervention scenario as the baseline, where costs = 1 and benefits = 1, with a ratio of 1. This implies that:
    - a no-intervention scenario delivers 48% less benefits for every dollar spent,
    - a with-intervention scenario delivers 27% less benefits for every dollar spent,
    - a catchment management and drains scenario gives the same benefits (1% less) for every dollar spent, and
    - a no-maintenance scenario offers similar returns as the no-intervention scenario (with 47% less benefits) per dollar spent.

BCA combining intervention and opportunity costs with published ecosystem value	2018 Pre-intervention	2028 Without intervention	2028 With intervention	2028 Catchment Management + Drains	2028 Intervention but no maintenance
PV of potential benefits: US$'000	6 273	5 560	3 387	4 815	3 316
Benefits relative to 2018 Pre-intervention	1.0	0.9	0.5	0.8	0.5
PV of costs: US$'000	285	442	441	407	434
Costs relative to 2018 Pre-intervention	1.0	1.5	1.5	1.4	1.5
Benefit Cost Ratio (for illustrative purposes only)	21.98	12.59	7.67	11.82	7.65
BCA combining intervention and opportunity costs with the Human Benefit Index	**2018 Pre-intervention**	**2028 Without intervention**	**2028 With intervention**	**2028 Catchment Management + Drains**	**2028 Intervention but no maintenance**
The level of Human Benefit Index	35 160	28 309	34 509	49 612	28 312
The magnitude of human benefit relative to 2018 pre-intervention	1.00	0.81	0.98	1.41	0.81
Human benefit index relative to cost (BCR)	1.00	0.52	0.63	0.99	0.53
Human benefit Index per US$1 spent	0.12	0.06	0.08	0.12	0.07

Table 4: Benefits and costs from two perspectives

In addition, the analysis also identified which ecosystems were delivering the greatest levels of benefits in the current time and how the benefits may change in the different scenarios (see Table 5). This analysis is useful for identifying management priorities.

Ecological assets contributing to human benefit events	Baseline	Changes relative to baseline			
	2018 Pre-intervention	2028 Without intervention	2028 With intervention	2028 Catchment Management + Drains	2028 Intervention but no maintenance
01 - Built-up urban settlement	3	-1	-0	4	-1
02 - Rocky shore	-	-	-	-	-
03 - Sandy Beach	2 289	-484	-126	504	-410
04 - Mangroves	-	-	-	-	-
05 - Sea Grass	1 912	-376	-367	341	-516
06 - Coral Reefs	21	0	-	2	-
07 - Coral debris algae reefs	3 981	-986	-675	1 203	-1 229
08 - Neritic zone	76	-17	11	46	-6
09 - Forest	20 603	-3 651	-1 959	6 868	-4 326
10 - Wetlands	511	-157	-78	52	-120
11 - Foreshore vegetation	5 656	-1 162	1 653	3 996	-287
12 - Canals / drains	77	-12	883	1 407	48
13 - Rivers	29	-5	7	29	-1

Table 5: Priority habitats for management – note the positive or negative symbols indicating the direction of change in future scenarios

The analysis shows that forests, foreshore vegetation, coral debris algae reefs, sandy beaches and sea grass are some of the greatest benefit generators. However, the changes to wetlands, together with climate change, are the major drivers of the condition of marine assets. Management of future marine water quality needs to focus on the important role of forests in addition to urban settlement impacts. Good water quality, with regular flows, generated by forests could mitigate future non-point source pollution and also offset the current loss of wetland functionality.

11 Conclusions

11.1 The supply of ecosystem services

- There are a wide range of services associated with or produced by the Petit Barbarons natural capital. This implies that intervening in the system impacts on numerous services and each will have its own suite of users.
- The habitats present in the impact area are closely interconnected. This implies that interventions need to consider impacts on a wide range of interconnected ecological and human processes.
- There are strong hydrological linkages between the different habitat types. The implication is that intervening in hydrological systems need to be informed by careful consideration of the direct and indirect impacts of water flows, associated chemical (organic and inorganic) and pathogen flows, and associated sediment flows.
- Much of the natural capital is in poor to moderate condition. This implies that the social-ecological system is unlikely to be resilient to future climate change perturbations, such as storm surges, sea level rise, intense rainfall events and flooding. The condition of the habitats implies that much can be done to promote resilience by improving the condition of the natural capital stock, thereby increasing functionality and elevating service supply levels.
- The natural capital at Petit Barbarons can play an important role in mitigating the impacts of climate change in Seychellois society, which includes:
    - Protecting built infrastructure and property values by preventing flooding, storm surge, landslides, coastal erosion and the loss of transport access. Note that these services are supplied at relatively moderate to low levels and are therefore going to grow in value as climate change manifests itself further in Mahé.
    - Enhancing built infrastructure values by providing amenity, sense of place and recreation opportunities. Note that these services are supplied at relatively high to moderate levels, and hence one sees a strong international demand for Mahé as a property investment and holiday destination. However, amenity and recreation services are supplied by many habitat types and implies that all the assets need to be secured by environmental management for Mahé to continue to be a global tourist destination. Climate change is likely to impact the beaches, foreshore vegetation and coastal infrastructure, all of which are critical for securing tourism. This implies climate change adaptation responses will need to focus on securing these assets.
    - The natural capital is capable of supplying a safe and healthy environment for residents and visitors to live in by assimilating human waste and promoting good water quality, with fewer pollutants and pathogens. This service is supplied at relatively high levels. However, climate change can reduce functionality and reduce these service levels, with elevated runoff and flooding, and the loss of wetland filtration.
    - Promoting resilient economic activities by supplying elevated recreation services, fish nurseries and fisheries. These services are supplied at a wide range of levels. Again, climate change may reduce these service levels and a special focus needs to be made to increase all these services so that they are more resilient to possible changes.
    - Promoting conservation of Seychellois biodiversity by promoting resilient ecological systems. These services are supplied at relatively high levels but are vulnerable to climate change.
- While climate change has the potential to degrade ecosystems and reduce service levels, it is the ongoing conversion of natural capital, over-use (harvesting) of ecosystems, increasing pollution discharge, infestation by alien species and water flow disruptions (alien plant evapotranspiration, accelerated runoff, abstraction

and diversion) which are currently running down the terrestrial and marine natural capital. The implication is that systemic environmental management is required to reverse current trends and to maintain or enhance natural assets to the point where they are capable to playing a decisive role in climate change mitigation. The failure to reverse current trends will imply that climate change impacts are compounded by environment degradation. This implies abundant natural capital services will need to be replaced by built capital services, using scarce financial capital. It is unlikely that this will be affordable, and maintenance of existing ecological infrastructure will be the cheapest option available to Seychellois society.

11.2 The demand for ecosystem services

- The Petit Barbarons area offers multiple benefits to multiple user groups, using an integrated social-ecological system, where no habitat or living natural asset is independent. Consequently, climate change interventions should consider changes to all service benefits in order to optimise human wellbeing in Mahé.
- Focussing an intervention on a single user group, such as flood reduction users, is likely to produce suboptimal outcomes in terms of human wellbeing and economic benefits.
- Prior to intervening, the Seychelles Government should identify which response will offer the greatest net benefit to society. In other words, which action will offer the greatest level of benefits per Rupee spent. This implies not doing a partial analysis, but a more comprehensive analysis that considers the costs and benefits to all service user groups.

11.3 The intervention scenarios

- A *2028 No Intervention* scenario will lead to a reduction in most of the Petit Barbarons ecosystem service levels. There could be a contraction in services of between 20% to 30%. This implies a future with more people and fewer services, with a decline in services per capita. Much of the decline is due to increased human pressure combined with climate change.
- A *2028 With Intervention* scenario indicates that the risk of rainwater flooding will be reduced, and property prices and transport access will be enhanced in the short term. However, the current interventions alone are unlikely to be adequate in the longer term, that is, in 10 years' time. Changes to wetland functionality due to the establishment of drains has negative impacts on the receiving ocean habitats, if they are not combined or offset with additional catchment management upstream of the flooding area. Consequently, government needs to consider alternative options.
- A *2028 Catchment Management and drains* scenario would accommodate the increased human pressure on the system in a changing climate and generate a net positive impact. Environment management together with site-specific interventions, are likely to promote a resilient Mahé society.
- A *2028 No Maintenance* scenario indicates that maintenance of the existing interventions is required to ensure that the intervention does not a generate net cost or loss to Mahé society.

11.4 The effects of interventions on risk

- The services at greatest risk are recreation, transport access, amenity and nature appreciation. The impacts of the climate change responses to risk are outlined below:

- Recreation – the risk to recreation is elevated with climate change and may not be significantly reduced by the current interventions. In addition, without maintenance, the current intervention could increase risk above a No-intervention scenario. In other words, society may be at greater risk than before if the interventions implemented are not adequately managed. However, a further investment in catchment management could significantly reduce risk levels, to even below current levels, despite future climate change, population growth and settlement growth. The risk to recreation could limit future tourism amenity and investment in this precinct, and similarly for other vulnerable locations in Mahé.
- Nature appreciation and visual amenity /sense of place – the risks and trends associated with visual amenity and nature appreciation are similar to recreation risk above, but of a lower magnitude.
- Transport access – the risk to transport access is elevated by climate change, however the current intervention can reduce this risk substantially. While the EbA intervention was planned to reduce the risk to homestead flooding, the impact on reducing transport access risk is much more significant. This is due to there being far greater numbers of road users than affected home owners and fewer buffers for road protection.

11.5 The costs and benefits of climate change interventions

- The present value of Petit Barbarons ecosystem benefits, in monetary terms, could have an orders-of-magnitude value of some US6.3 million.
- The present value of current opportunity costs of flooding at Petit Barbarons could amount to some US285 000.
- The intervention and opportunity costs of the scenarios show that the 2028 Without intervention scenario has the highest costs. In other words, the highest costs are likely to be incurred by doing nothing. The 2028 Catchment Management and Drains scenario has the least total costs despite incurring more intervention costs. This is due to the greater reduction in recurring damage costs, as the upstream catchment improves. Note that this scenario also has less costs than a no-maintenance scenario, implying that not spending on maintenance is false economy.
- The current intervention is likely to keep human benefits similar to current levels. This is largely an engineered option. While floods get reduced for some households, other service users suffer losses due to negative climate change impacts and due to the loss of wetland functions.
- Without an intervention, human benefit levels may decline by some 19%.
- The current intervention, combined with catchment management (a hybrid option), could result in a 41% increase in human benefits, countering climate change losses and offsetting the loss of wetland functionality.
- Importantly, not maintaining the current intervention is likely to result in benefit levels similar to the no-intervention scenario.
- The analysis shows that forests, foreshore vegetation, coral debris algae reefs, sandy beaches and sea grass are some of the greatest benefit generators. However, the changes to wetlands, together with climate change, are the major drivers of the condition loss in marine assets. Management of future marine water quality needs to focus on the important role of forests in addition to urban settlement impacts.

11.6 The implications of the analysis

- The implications for climate change adaptation is that the current interventions at Petit Barbarons are:
    - Able to significantly reduce transport access risk, but

    - May not significantly reduce the risk for recreation, nature appreciation and amenity – which are some of the critical services underpinning the Mahé tourism economy.
    - The current intervention is necessary but not sufficient secure the areas’ economic drivers and associated human wellbeing in the long term.
- Catchment management is a necessary addition to the current interventions, to ensure that abundant natural capital services are available in the long term and do not need to be replaced by built capital services, using scarce financial capital. The highest costs are likely to be incurred by doing nothing. The Catchment Management and Drains scenario has the least total cost despite incurring more intervention costs, due to the reduction in recurring damage costs. This scenario also has less costs than a no-maintenance scenario, implying that not spending on maintenance is false economy in the long term.

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