

SEYCHELLES

Post-Tsunami Environmental Assessment



UNEP

United Nations Environment Programme

Published in November 2005
© 2005 United Nations Environment Programme
ISBN: 92-807-2654-4
Job No. DEP/0759/GE

Graphics by: Global Resource Information Database (GRID) Arendal/Viktor Novikov
Layout by: DJEnvironmental, UK
Printer: SADAG France

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Cover: (Front) Submerged fishing boat, Seychelles. Damage to boats, nets and other fishing gear was among the major impacts of the 26 December 2004 Indian Ocean tsunami (credit: B. Curtsinger/National Geographic Image Collection. (Back) Road swept away by the tsunami; the photograph was taken from the repaired section (credit: M. de Vries).



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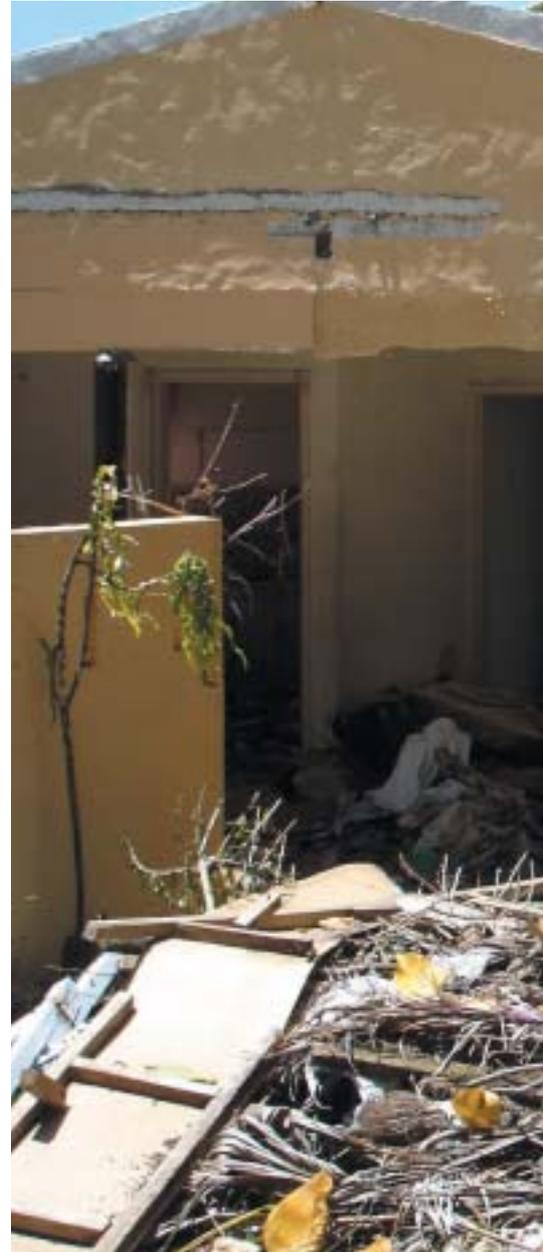
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Narrow beaches and vulnerable near-beach development of tourism facilities.
Credit: M. de Vries





EXECUTIVE SUMMARY



A house damaged by the impact of the tsunami surge.
Credit: M. Collins



The Seychelles island group was struck by a series of powerful tidal surges, resulting from the tsunami, generated by the earthquake off Indonesia on 26 December 2004. As a direct consequence of these tidal surges two people lost their lives, and hundreds of families suffered damage to their homes and livelihoods. The effects of the tsunami were compounded by exceptionally heavy rainfall on 29 December, causing flooding, landslides, and tree/rock falls.

The Seychelles are globally recognized for the richness of their marine and terrestrial ecosystems, which in turn support the islands' main economic activities; tourism and fishing. There was concern that in addition to its direct impacts on human communities, the tsunami may have caused damage to the islands' environmental values, thereby indirectly affecting livelihoods.

In response to a request from the Government of the Republic of Seychelles, the UNEP Asian Tsunami Disaster Task Force organized a Rapid Assessment Mission to Seychelles at the beginning of February 2005. The mission team conducted site visits and held meetings with key stakeholders, both governmental and non-governmental, with an interest in management of the islands' environment and natural resources.

The team concluded that the principal environmental impacts had largely been confined to the granitic inner islands, which include the main centres of population on Mahé, Praslin and La Digue, with the outer islands apparently escaping relatively lightly due to the physical shelter provided by the Seychelles bank.

The main categories of environmental impacts recorded were:

- severe damage to beaches, including west-facing coasts in some areas;
- severe damage – approaching 100% in places – to granitic island coral reefs on carbonate substrates exposed to the north and east, with less damage to reefs on a granitic substrate;
- serious damage to coastal vegetation, including many fallen and severely destabilized trees;
- some damage to sea-grass beds (due to smothering by sediment) and other marine and coastal ecosystems, including those such as wetlands that protect the coastline from erosion and flooding;
- discharge of sewage from a fractured pipeline into coastal wetlands on Mahé; and
- significant quantities of debris washed up along the shore.

Significantly, shoreline damage was focused where deep channels lead through or up to the fringing coral reefs, focusing and amplifying the wave energy at these points. Thus, two of the primary assets of the fringing reefs – shelter and access to the open ocean – have encouraged coastal development just above the high tide line, but the access channels also increased vulnerability to the tsunami (and therefore to other wave, tide and storm-related threats). This risk will only intensify with climate change, due to rising sea level and increasing extremes of weather. The pattern of tsunami damage serves as an indicator of future vulnerability, unless appropriate measures are taken.

A rapid cost assessment of repairing the damage caused by the tsunami was conducted by the Government of Seychelles in January 2005. This resulted in a total estimate of USD30 million, but only USD1.3 million were budgeted for responding to the environmental impacts.

The UNEP rapid environmental assessment drew the following general conclusions based on site visits and discussions with Seychelles organizations:

- the tsunami damage in the Seychelles is extensive, the response of authorities has been speedy and thorough, in this way limiting secondary impacts. It is especially relevant to mention the inherent limitations of the islands' human, technical and financial resources. Government disaster management programmes have shown



A clogged beach-side discharge channel.
Credit: M. de Vries

resilience during the tsunami but were stretched to the limit of local operational capabilities. Sound waste management limited the load of waste and pollution reaching the sea;

- it is clear that beach-crest and coastal vegetation were very important in reducing the impact of the tsunami wave, due to their role in sediment stabilization, sand trapping and wave attenuation. The maintenance and expansion of mangroves and coastal vegetation is important for reducing the vulnerability of the coastal zone to erosion and impacts of severe storms and tidal surges;
- the damage caused by the tsunami and the severe rainfall of December 2004 must be seen in the context of increasing frequency over recent decades of the impacts from other natural hazards, including fires, landslides, storms, drought, rising sea level, and rising ocean temperatures. These threaten the functioning of the marine and terrestrial ecosystems which are the lifeblood of the Seychelles economy and of worldwide importance.

UNEP recommends that action in response to the tsunami should involve wider activities to secure long-term sustainable management of the Seychelles natural environment. In addition to direct repair and mitigation measures, action is needed to:

- design and implement an extensive capacity-building programme for the key stakeholders involved in managing the Seychelles environment;
- identify and implement an ecologically sustainable means of ensuring that the coastline is as resilient as possible to the impacts of increased storminess and rising sea levels, both predicted as consequences of global climate change; and
- design and implement robust environmental monitoring and early-warning systems.

Given the richness of the marine and terrestrial ecosystems, as well as the commitment of Seychelles to Integrated Coastal Zone Management and the just management of their nature, Seychelles has an opportunity to present itself as an example of a Small Island Developing State in preserving its beauty, reducing disaster and laying out a credible way forward to sustainable development.

INTRODUCTION



Rock formation on Curieuse island.
Credit: M. de Vries



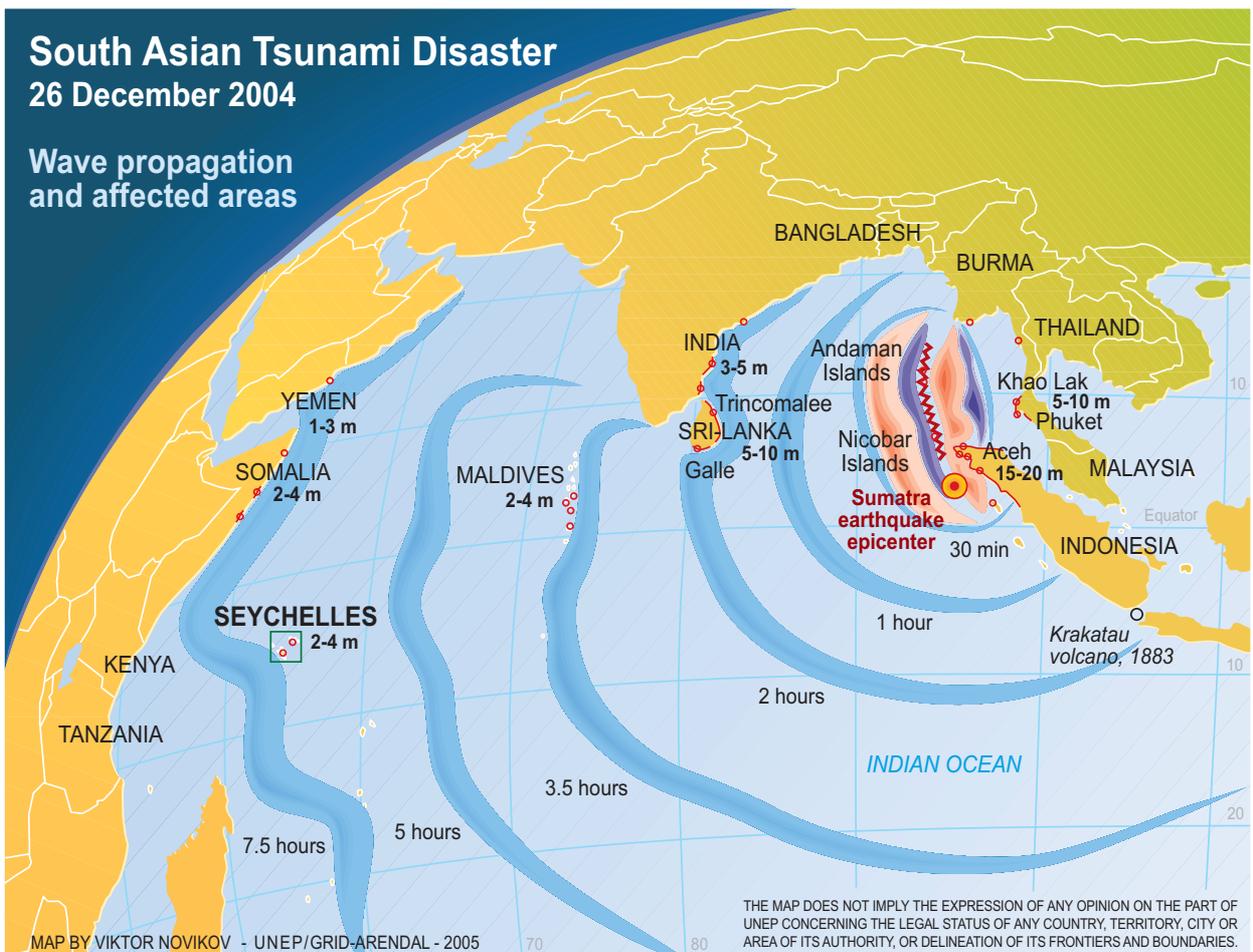
1. INTRODUCTION

1.1 Republic of Seychelles – key facts

Geography

The Republic of Seychelles comprises a group of about 115 islands located across 1.3 million square kilometres of the western Indian Ocean, centred some 1,600 km east of mainland Africa, and lying between 4 and 11 degrees south of the equator. Its land area covers 455 km², while the coastline is around 490 km in length. A total of 41 islands are granitic with rugged topography. They include the so-called ‘inner islands’, of which Mahé (155 km²), Praslin (38 km²) and La Digue (10 km²) are the most economically developed. All the granitic islands are situated within a distance of 50 km from Mahé and Seychelles’ capital city, Victoria. The rest of the islands are coralline, rising only a few metres above sea level, and scattered throughout the western Indian Ocean.

More than 95% of the estimated 85,000 inhabitants live on the three inner islands of Mahé (86%), Praslin (8%) and La Digue (2%). The population density on these three islands is 468 inhabitants per square kilometre.



⚡ The aftershock zone Sumatra-Nicobar 📏 High water level 📏 Low water level 📍 Major tsunami-affected areas 1-2 m - wave height

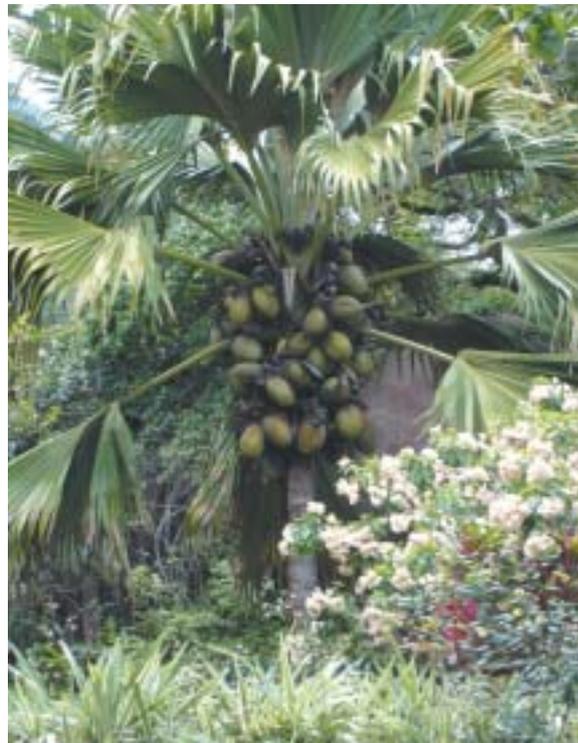
Sources: NOAA 2005, UNEP 2005, IOC 2005, National Geographic 2005

A 2003 World Bank estimate puts per capita GDP at USD7,480. The two most important economic sectors are tourism, which employs over 30% of the labour force and generates around 70% of the nation's hard currency earnings, and fisheries (including processing, packaging and export). Both of these key industries clearly depend for their future prosperity on the continued health and sustainable management of the islands' coastal and marine ecosystems.

The official website of the Republic of Seychelles can be found at www.virtualeseychelles.sc

Environmental significance

The Seychelles form part of the 'Madagascar and Indian Ocean Islands Biodiversity Hot Spot' recognized by Conservation International as one of the 25 most important areas for biodiversity on the planet. The islands also constitute a Centre of Plant Diversity, as recognized by IUCN – The World Conservation Union, and include two Endemic Bird Areas listed by BirdLife International. The most important ecosystems include coastal and marine habitats, especially coral reefs (total area approximately 1,690 km²), mangroves and sea-grass beds, and terrestrial habitats, notably natural and semi-natural forests which cover up to 90% of the land area.



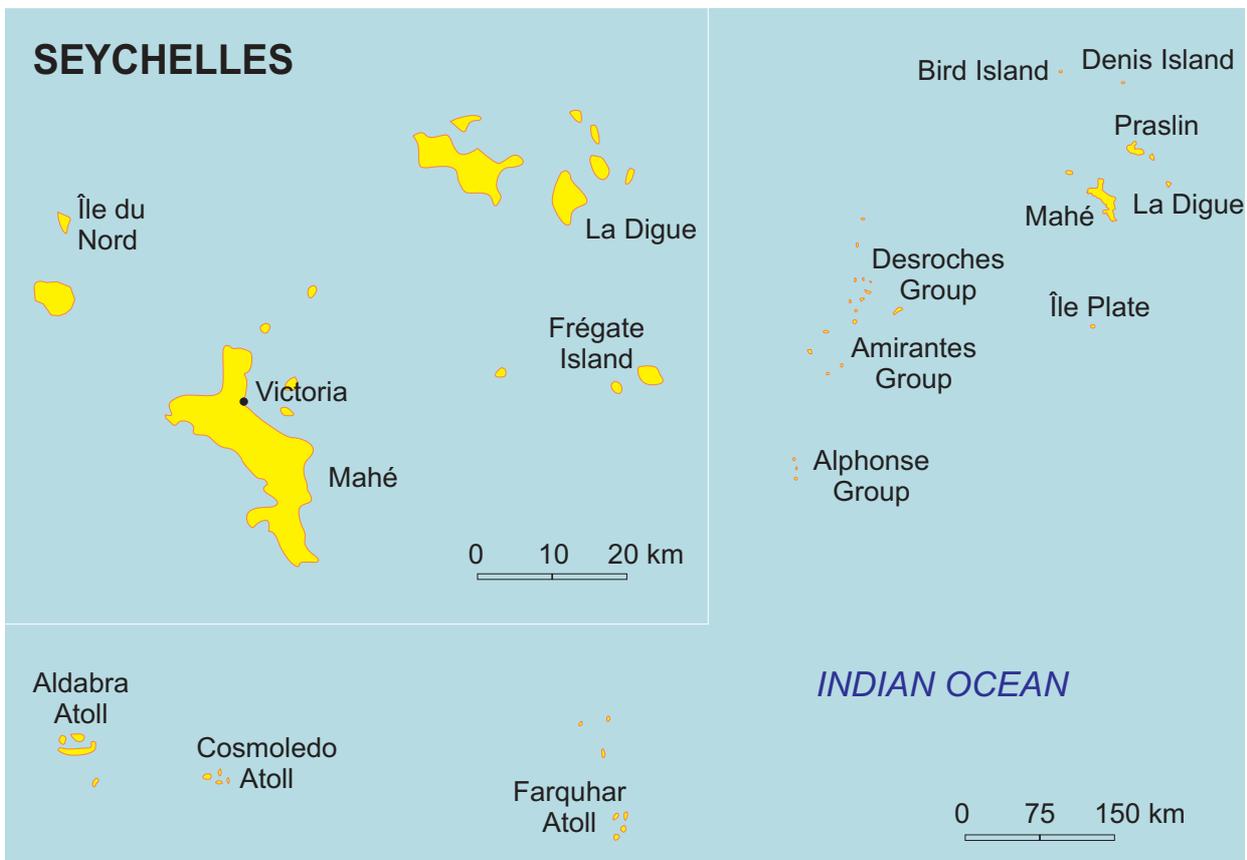
Female Coco-de-mer palm.
Credit: M. Collins

Environmental pressures

The unique environmental values of the Seychelles are under great pressure from various development sectors (e.g. tourism, agriculture/agro-forestry, industry, housing and transport infrastructure). This pressure is highest on the coastal plain where over 80% of the republic's flat land occurs, including that with the highest development value. Terrestrial and semi-terrestrial ecosystems in coastal regions are therefore most at risk. These include lowland woodland, dunes, beaches, freshwater wetlands and mangroves. At the same time, marine and coastal ecosystems are threatened by the effects of climate change, including increasing extremes of weather, rising sea level and rising sea temperatures. Coastal habitats may be squeezed between land-based development and rising sea level, while the Seychelles coral reefs have already been extensively damaged by coral 'bleaching' due to rising sea temperatures. Seychelles currently lies outside the cyclone belt, so severe storms are experienced only rarely but, as demonstrated on 29 December 2004, devastating extremes of weather do occur.

1.2 The tsunami of December 2004

The tsunami that struck the Republic of Seychelles on 26 December 2004 had travelled about 5,000 km from the epicentre of the earthquake zone, offshore from the Indonesian island of Sumatra, in less than seven hours. By mid-day on 26 December an extreme low tide occurred throughout the inner Seychelles. At 13.00 hours tidal waves ranging from 2.5 m to 4 m in height came ashore on the east coast of Praslin and Mahé islands. Fortunately, these waves lacked the catastrophic energy of those in the eastern Indian Ocean, but their effects were nevertheless felt all along the east coast of Mahé. Refracted waves hit the west coasts of Praslin and Mahé 30 minutes to one hour after the respective east coasts were hit. A second tidal surge occurred at 17.00 hours, followed by two smaller ones at 22.00 hours and 05.00 hours on 27 December. The second surge had more or less the same effect as the first because, although smaller, it occurred at high tide. The two smaller waves caused known damage only on the west coast of Praslin.



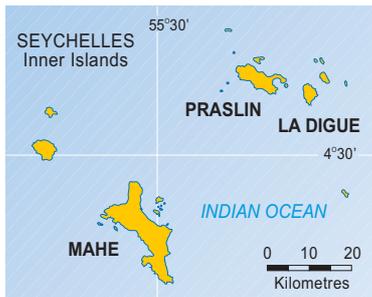
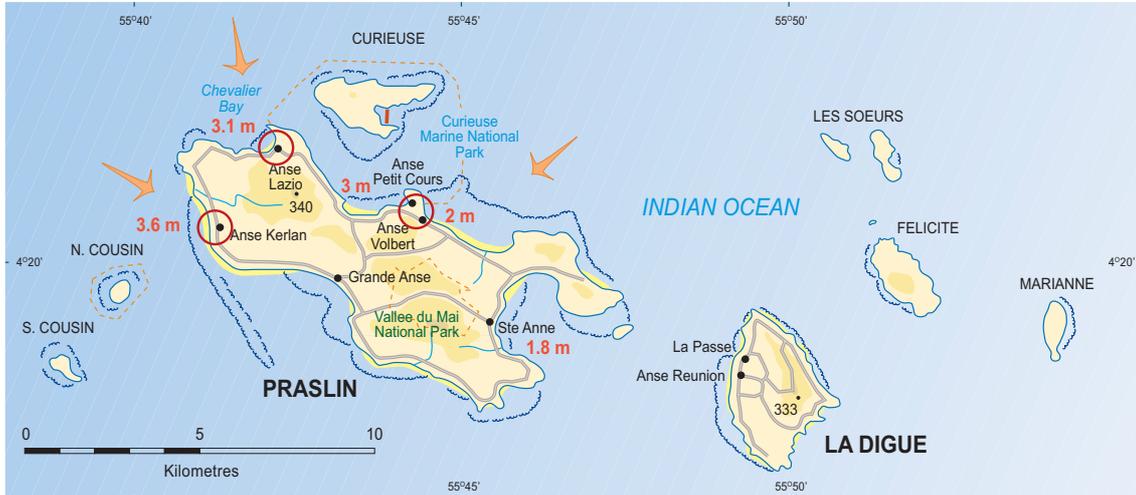
The tidal surges flooded low-lying areas of Mahé, Praslin and La Digue and caused widespread damage to houses, roads, bridges, other infrastructure, beaches and coastal vegetation. The flooding persisted for a period of about six hours. Two people lost their lives, while hundreds of families sustained severe damage to their properties and/or livelihoods. The fact that the tsunami occurred on a Sunday has been widely cited as one reason why the loss of life was not much higher; for example, most fishermen do not put to sea on Sundays. Further, the first tidal surges also occurred prior to the expected afternoon peak in beach use.

Many of the remote outer islands of the Seychelles group are either sparsely inhabited or not inhabited at all. At the time of the Rapid Assessment Mission, status reports were still coming in from these areas, but subsequent information suggests that damage from the tsunami was relatively slight, with the southern and western islands benefiting from the shelter provided by the Seychelles bank.

The direct impacts of the tsunami were compounded – and the clean-up operation severely hampered – when extreme rainfall occurred on 29 December. Up to 250 mm were recorded in northern and central areas of Mahé and heavy rains continued for several days. Runoff from the hills formed virtual rivers that swept across the countryside, causing widespread landslides, tree and rock falls, particularly in the worst-hit parts of northern and central Mahé, resulting in further damage to housing and infrastructure, as well as to protective hillside vegetation cover.

Seychelles

Features of the 26 December 2004 tsunami



Key populated areas

- Victoria - national capital
- Settlements

Natural features

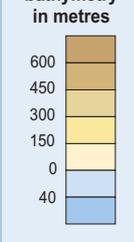
- Coral reefs
- Reclaimed lands
- Protected areas
- Rivers, lakes and lagoons

Tsunami impacts

- Approximate direction of the tsunami waves
- 2 m Surveyed highest flood water level marks
- Areas badly hit by the tsunami due to high wave heights, low beach berms, and concentration of human activities

Estimated arrival date and time of the first series of waves is 26 December 2004, 12.10-12.30 am local time (-4 h UTC)

Elevations and bathymetry in metres



THE MAP DOES NOT IMPLY THE EXPRESSION OF ANY OPINION ON THE PART OF UNEP CONCERNING THE LEGAL STATUS OF ANY COUNTRY, TERRITORY, CITY OR AREA OF ITS AUTHORITY, OR DELINEATION OF ITS FRONTIERS AND BOUNDARIES.

UNEP/GRID-ARENDAL - 2005

Sources: Seychelles Ministry of Environment 2005, UNEP Seychelles Assessment Team 2005, UNESCO International Oceanographic Commission 2005

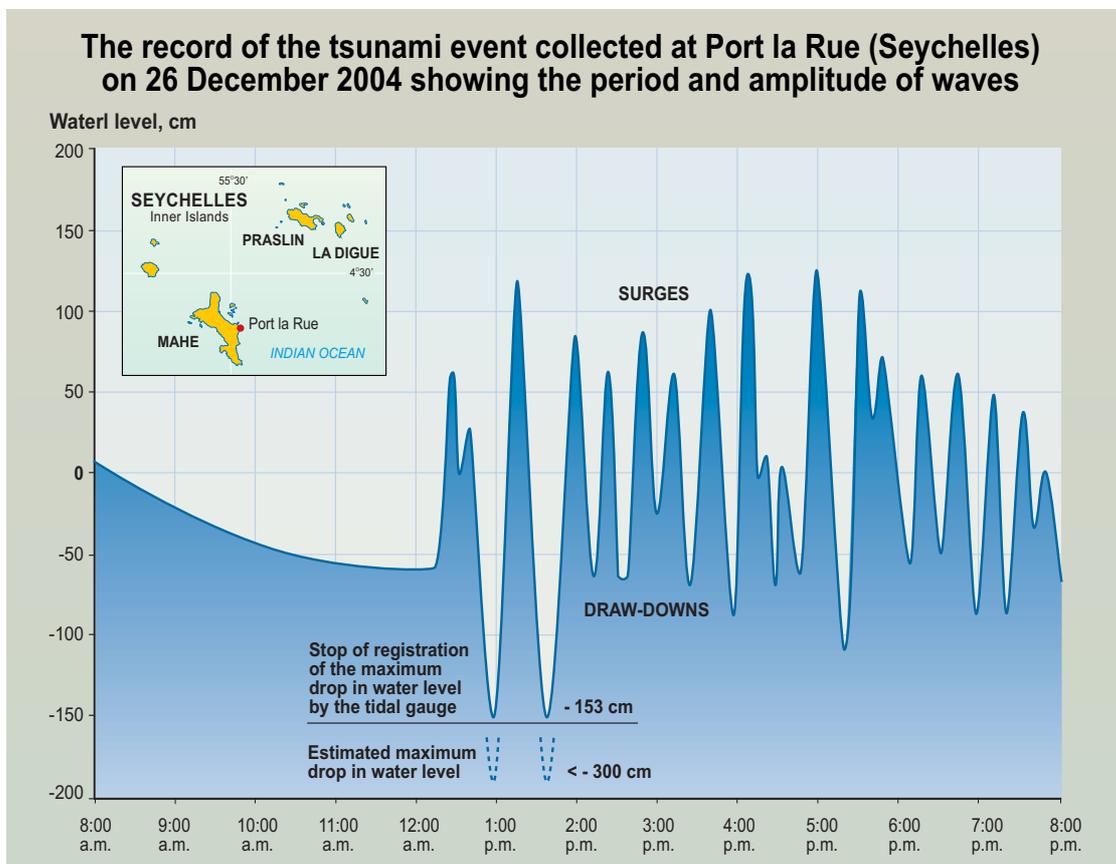
1.3 UNEP Post-tsunami Rapid Assessment

Background

On 21 January 2005, following discussions at the Mauritius meeting of Small Island Developing States (SIDS), UNEP's Executive Director, Klaus Töpfer received a request from President Michel of the Republic of Seychelles for technical and financial assistance in conducting a rapid assessment of the environmental impacts of the tsunami, focusing on:

- understanding the long-term consequences for marine and coastal ecosystems;
- rehabilitating the services of the Marine Parks Authority;
- addressing the stability of the coastline as a result of the wave surges; and
- assessing current levels of disaster preparedness, including early-warning systems.

As the first stage in responding to this request, UNEP organized a fact-finding mission to Seychelles during the period 3–10 February 2005, coordinated by the UNEP Asian Tsunami Disaster Task Force. This report presents the conclusions and recommendations of the fact-finding mission.



Sources: University of Hawaii Sea Level Centre 2005, UNESCO International Oceanographic Commission 2005

Table 1. Key stakeholders in the Seychelles natural resource sector

Stakeholder	Key assessment theme(s) relevant to stakeholder
Ministry of Environment of Natural Resources: Pollution Control & Environment Impacts Division Crop Development & Promotion Division Policy Planning & Services Division National Parks and Forestry Coastal Zone Management Unit Wetland Unit	Environmental resources legislation Waste management Agriculture and soils Protected areas Wetlands and coastal zones
Ministry of Tourism & Transport, Land Transport Division	Drainage
Ministry of Land Use and Habitat: Landscape Management Division Centre for Geographic Information Systems	Land use and soil Mapping
Seychelles Centre for Marine Research and Technology – Marine Park Authority	Coral reefs Mangroves Sea-grass beds
Seychelles Fishing Authority	Fisheries (commercial and artisanal)
Public Utilities Corporation	Freshwater Sewage
Nature Seychelles	Environmental resources
Island Conservation Society	Environmental resource
Seychelles Island Foundation	Environmental resources
Marine Conservation Society Seychelles	Marine environment
Underwater Dive Centre	Coral reefs
IMF	Impact on Seychelles balance of payments
UNDAC	Disaster assessment
UNDP	Damage to coastal infrastructure
World Bank	Impact on Seychelles balance of payment
Canadian Government	Wave heights
Japanese Government	Early-warning training

The terms of reference for the mission were based on the original presidential request, as well as subsequent discussions with the Ministry of Foreign Affairs, the Ministry of Environment and Natural Resources, and the National Disaster Secretariat.

At the same time as the February 2005 UNEP fact-finding mission, UNDP mobilized a mission to Seychelles to assess humanitarian and infrastructure needs. Members of the UNEP mission met with the UNDP Team Leader to discuss and clarify respective roles.

UNEP's partners and key stakeholders

There are a large number of stakeholders in the Seychelles natural resources sector, spread across governmental, non-governmental and private sectors (see Table 1). In addition to the great interest shown by the President's Office, the Ministry of Environment and Natural Resources bears key responsibilities. These include forestry, crop development, national parks and botanical gardens, biodiversity conservation, pollution control and waste management, environmental impact assessment, coastal management, hydrology and meteorology. Fisheries are managed by a parastatal corporation, the Seychelles Fishing Authority. Also of great importance is the Seychelles Centre for Marine Research and Technology-Marine Parks Authority (SCMRT-MPA), a governmental body responsible for many aspects of research and conservation in the coastal zone. In the private sector, the fishing industry is the largest if refrigeration, canning and distribution are included in the figures. The second most important sector is tourism, with the Seychelles being a major international destination. The non-governmental sector includes several closely related organizations such as the Marine Conservation Society of the Seychelles and Nature Seychelles. These are relatively small but benefit from the support of a Liaison Unit for NGOs of the Seychelles (LUNGOS) that provides information and communications backup.



UNEP/Government of Seychelles assessment team.
Credit: M. Collins

Assessment methods and approach

The Rapid Assessment Mission comprised six members and took place during the period 4–9 February 2005. Recognizing that the assessment had to be rapid, strategic in scope and based on readily available information, the team was deployed in three main ways:

- meetings and interviews to acquire available information from government officials, scientists and NGOs, including reports, maps and GIS products (see Annex IIA for a list of the key individuals contacted);
- site visits (on the main inhabited islands of Mahé, Praslin and Curieuse only) for familiarization sufficient to reach general conclusions on the level of impact and rehabilitation needs, and to acquire photographic data (see Annex IIB for list of sites visited); and
- report preparation and presentations of provisional findings to government officials and the media.

The team split into two groups for the purpose of field visits, with two members concentrating on marine ecosystems, while the remaining four were land-based. Coral reefs and marine habitats were assessed primarily through existing status assessments housed at SCMRT-MPA, together with a preliminary reef survey conducted by SCMRT staff assisted by IUCN in January and February 2005.

The team focused on:

- gathering examples of damage or contamination caused directly by the tsunami;
- economic valuation of the environmental impact;
- evidence of socio-economic or livelihood impacts of the tsunami;
- the underlying state of the environment before the tsunami;
- assessment of the importance of ecosystems in buffering and protecting the coastline;
- interlinkages between sectors; and
- lessons learned for environmental management in relation to disasters.

It should be noted that two members of the team continued with coral reef assessment until 13 March 2005, under the aegis of the IUCN Global Marine Programme and the Coral Reef Degradation in the Indian Ocean Programme (CORDIO). This included stakeholder consultation and site visits to the granitic inner islands of Felicite, La Digue, Ste Anne, Isle Coco and St Pierre, as well as Mahé, Praslin and Curieuse.

Geographical scope of the assessment

As described above, the Seychelles comprise an inner, inhabited, granitic island group, and an outer, widely dispersed and largely uninhabited coralline group. While the inner islands rise to several hundred metres, the outer islands reach only one to two metres above sea level. Owing to time constraints and the need to prioritize areas where environmental damage was most likely to have impacted directly on human health and livelihoods, the mission excluded the outer islands and concentrated exclusively on the inner islands. However, the low-lying outer islands are clearly at risk from tsunamis, severe weather events and sea-level rise. As stated above, reports available after the UNEP mission suggest that the outer islands had been relatively unaffected by the tsunami. In addition to the limited geographical scope of the assessment, some additional gaps are summarized below.

Assessment gaps

Owing to its focus on coastal and marine ecosystems, the mission was unable to observe or assess impacts of the post-tsunami storms on steeply sloping inland areas, including forests, where landslips and rockfalls are common. Similarly, little information could be gathered on the impact of saline intrusion on groundwater and coastal soils, including those used for agriculture and fruit growing.

In the marine environment, the main gaps relate to less well-known habitat types, such as sandy subtidal substrates (which could have been severely impacted by mixing), and the more remote island and bank reef ecosystems.

The mission interviewed only two of Seychelles' many NGOs, which are loosely linked through LUNGOS. There remain significant opportunities for mobilizing, supporting and building capacity among both humanitarian and environmental NGOs in support of natural hazard mitigation.

There was insufficient opportunity to consult with the fishing industry, in terms of either the private sector or the artisanal community – both key stakeholders in future environmental management actions.

There was no opportunity to consult with the tourism sector, which has a great deal at stake in Seychelles and is clearly another key stakeholder in planning for the future.

FINDINGS: IMPACTS OF THE TSUNAMI



Peer damage caused by the tsunami storm surge.
Credit: M. de Vries



2. FINDINGS OF THE TSUNAMI

2.1 Overview of key environmental impacts of the tsunami

Based primarily on the site visits conducted during the mission (see Annex IIB), but also on the outcomes of meetings and document review, the team members concluded that:

- Mahé and Praslin experienced the most significant impacts of the tsunami;
- other, less-populated, granitic islands, including Curieuse, La Digue, Felicite, St Pierre and Isle Coco were also directly affected; and
- the outer, less-populated coralline islands, especially those furthest to the south and west, were relatively little affected.

The principal environmental impacts (i.e. excluding damage to housing and other infrastructure) included:

- severe damage to beaches, including on west-facing coasts in some areas;
- severe damage to granitic island coral reefs on carbonate substrates exposed to the north and east, with less damage to reefs on a granitic substrate;
- some serious damage to coastal vegetation, including many fallen and severely destabilized trees;
- some damage to other coastal ecosystems such as sea-grass beds;
- some damage to ecosystems, for example siltation of wetlands, that protect the coastline from erosion and flooding;
- debris washing up on shorelines; and
- damage to urban landscapes in Victoria and elsewhere on Mahé.

More detailed information is contained in Table 2.

2.2 Rapid assessment of mitigation costs

A rapid assessment of the overall impact of the tsunami was conducted by the Government of Seychelles in January 2005.¹ Efforts were constrained by the immediate need to focus on disaster relief and clean-up in the aftermath of the tsunami and subsequent torrential rains, and by the limited number of staff in agencies that have multiple responsibilities. Nevertheless, initial assessments of economic losses, taking into account damage to roads, fishing boats and infrastructure, agriculture, public utilities, schools, reclamation land, houses, sports facilities and tourism establishments were undertaken. The total cost of rectifying the damage caused by the tsunami was assessed at USD30 million.

The Seychelles Department of Environment, Ministry of Environment and Natural Resources undertook a preliminary estimate of damage to the environment.² This covered damage to shorelines, vegetation and

¹ Government of Seychelles. 2005. Preliminary Report on the Effects of the Tsunami of the 26 December 2004 on the Inner Granitic Islands of Seychelles.

² Seychelles Department of Environment, Ministry of Environment and Natural Resources. 2005. Preliminary assessment and evaluation of damages cause by the sea-level rise of the Sumatra Earth Quakes on the Environment Sector.

Table 2. Summary of UNEP’s preliminary findings and gaps identified

Environmental component	Preliminary findings	Gaps identified
Coral reefs	Less than 5% damage. Main impacts on destabilized reefs. 90% of total areas were already damaged by coral bleaching.	Major impact sites of four inner islands covered qualitatively. Outer islands have not been checked.
Mangroves	Less than 1% direct damage. Burial by sand and silt. Scouring of channels.	Major impact sites covered.
Sea-grass beds	Less than 5% damage by smothering.	Major impact sites covered.
Beach vegetation	Less than 5% damage. Impacts by salinization of groundwater.	Major impact sites covered.
Coastal erosion	Erosion has been exacerbated at impacted locations. Continuous beach erosion is an increasing problem at many locations in the Seychelles.	25 erosion hotspots are known. Need for design and planning of solutions.
Saline water intrusion	Agricultural areas in the coastal plains encounter salinization of groundwater. Heavy rains have been reducing this problem.	Affected areas have been visited. Long-term damage of fruit trees and crops unknown.
Protected areas	All marine parks surrounding inner islands have been affected in some way. Park monitoring infrastructure on Curieuse Marine Park has been damaged.	The parks of the outer islands, including private reserves, have not been assessed.
Sea turtles, marine mammals and Giant Tortoises	No evidence of harm to adult sea turtles, but nesting beaches are affected by erosion and creation of beach cliffs. No indication of any adverse impacts on marine mammals or on Giant Tortoises.	Full impact on turtle nesting may not be known for some time.
Solid waste and sanitation	Amount of debris was limited. Most debris has been cleared shortly after the event. One sewage spill was caused by a broken transport pipe.	No gaps identified.
Institutional framework	Ministries and governmental institutions have cooperated swiftly and effectively to cope with tsunami damage.	The team interviewed a limited number of stakeholders.

‘environmental infrastructure’ such as pavements and municipal parks, and resulted in a total estimate of USD1.3 million. This sum included a budget of USD180,000 for coastal defences. This is considered to be a serious underestimate of the full cost of stabilizing and protecting coastal ecosystems in Seychelles, which will undoubtedly be confronted with more environmental emergency situations in the future.

The UNEP mission’s much higher rehabilitation estimates (see Annex 1) arose principally from greater recognition of the need to combat coastal erosion, an issue that was brought into sharp focus during a visit to Anse Kerlan beach on Praslin Island. The rehabilitation costs for this single, eroding beach range from USD0.5 million to USD1.4 million, depending on the type of protection assumed. Anse Kerlan is just one of 25 beaches affected by coastal erosion. Taking into account damage likely to result from future sea-level rise, rising sea-surface temperatures and intensified rainfall, drought and storm waves, a short- to medium-term programme of measures might entail basic costs of about USD3.9 million, while a preliminary estimate of USD26–52 million would be more appropriate for execution of all coastal stabilization measures required in the long term. The latter figure is intended to cover monitoring, early-warning systems, erosion control, ecosystem and biodiversity conservation, legal work and capacity building.

The government’s damage assessment included a budget for assessing impacts to coral reefs, fish stocks and mangrove systems but did not include estimates for repairing damage to these systems. On 20 January, SCMRTPA started a rapid assessment of impacts to ecosystems within marine protected areas, focusing on coral reefs and sea-grass beds. UNEP’s findings and recommendations take the results of this assessment into account, as well as additional information on damage to coral reefs, fish stocks and mangrove systems.

2.3 Impacts of the tsunami on specific ecosystems and habitats

Coral reefs, sea-grass beds and sandbars

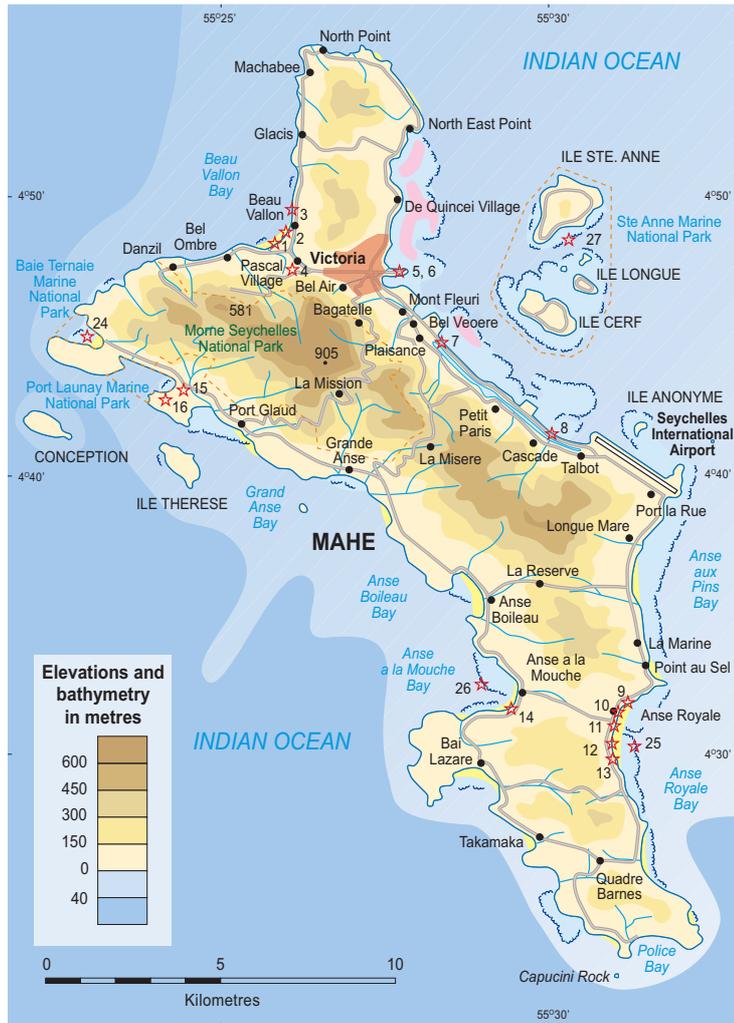
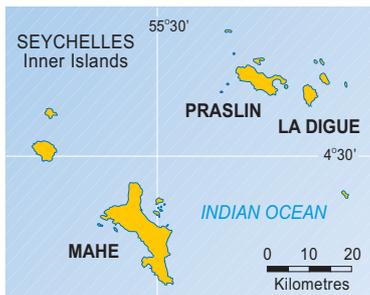
Fringing coral reefs around the central granitic islands have allowed the development of fine sand beaches and lagoons, and human settlement of the sheltered coastal plains behind them. Channels through the fringing reefs provide access from safe harbours to the ocean for artisanal fishing boats and pleasure craft. A healthy reef will adjust to changing sea levels and therefore keep providing these services to the human population. The primary infrastructure that supports the Seychelles’ tourism industry is provided by coral reefs, including beach activities, snorkelling and scuba-diving. Due to stresses from development and overfishing, and the El Niño-induced mass coral bleaching of coral reefs in the Indian Ocean in 1998, many of the granitic islands’ coral reefs were already significantly degraded before the tsunami. This in itself can cause increasing risk of hazards from waves and currents in the coastal zone.

Impacts of the tsunami on coral reefs were strongly modified by two factors: the geographic location of the islands and reefs and the substrate type of the reef (granitic versus biogenically-derived calcium carbonate). First, the northern and easternmost islands (in the Praslin-La Digue group) suffered the greatest damage to coral reefs due to their direct exposure to the tsunami. Sites on Mahé were sheltered by the outer islands and dissipation of wave energy over the shallow Seychelles banks. Second, reefs with a granitic base showed no negligible damage, while those formed by coral-derived calcium carbonate (old coral growth, sand etc) showed high levels of damage.

Damage on land was closely correlated with coral reef location. Fringing reef crests protect against normal waves. However, in the case of the tsunami, major terrestrial and coastline damage was located in areas sheltered by fringing reefs, for example at Anse Royale and Anse la Mouche on Mahé, Anse Petite Cours on Praslin and by the sea wall in Curieuse Marine Park. At these locations, damage was focused near deeper channels that allowed the waves to break closer onshore. Thus two of the primary assets of the fringing reefs – the combined shelter and ocean access that have allowed coastal development just above the high tide line – were also the reason for vulnerability to the tsunami, and thereby also to other wave- and storm-related threats. Deterioration of reefs will certainly make matters worse in coping with these hazards in the future.

Seychelles

UNEP visited sites



Key populated areas

- Victoria - national capital
- Settlements

Natural features

- Coral reefs
- Reclaimed lands
- Protected areas
- ~ Rivers, lakes and lagoons

UNEP field visit and damage survey

- ★ Location of visited sites

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Source: UNEP Seychelles Assessment Team 2005



Coral reef with tsunami abrasion damage (white patches).
Credit: D. Obura

Coral reefs and sea-grass beds

Eight islands in the Seychelles were monitored for damage that may have been caused by the tsunami. This work was conducted by teams of staff and rangers from SCMRT-MPA in January/February 2005 and site-by-site summaries are provided in Annex IIB. Coral reef damage in the inner Seychelles islands was predominantly caused by physical breakage due to waves and surge, mainly on loosely consolidated carbonate reef frameworks, with secondary damage to corals growing on these reef structures. These frameworks were already weakened by mass coral mortality in 1998, low recovery of corals since then, and ongoing bio-erosion and rubble movement.

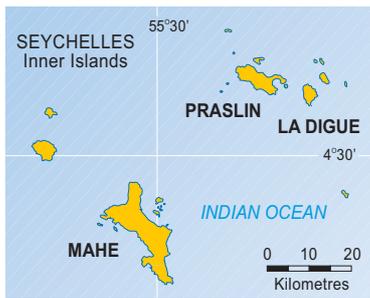
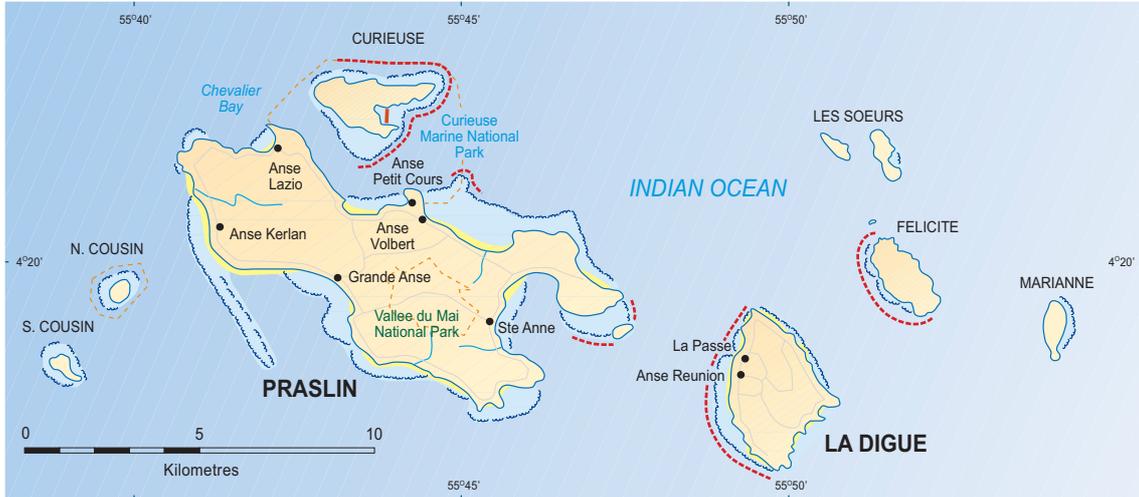
The geographic location of each island strongly influenced the degree of damage. The northern islands clustered around Praslin (including Curieuse, La Digue, Felicite and the rocks of Isle Coco and St Pierre) showed very high levels of damage – approaching 100% – on the carbonate reef substrates mentioned above. By contrast, sites around Mahé, including carbonate reefs damaged during the El Niño-induced bleaching of 1998, showed much lower levels of impact – generally below 10% – due to the shelter provided by the outer northern islands and dissipation of wave energy as the tsunami travelled over the greater distance of shallow water from the outer edge of the banks to Mahé.

Granitic reefs suffered less damage than reefs with a calcium carbonate (limestone) substrate. Granitic surfaces were either immovable as they form the bedrock of the islands, or, in the case of boulders and rocks, were too dense and/or of too compact a shape to be displaced by the force of the tsunami. Even on carbonate rock surfaces that were consolidated and firm, attached corals showed little breakage and mechanical damage or overturning.

Tsunami damage to the loosely consolidated reef frameworks previously damaged by mass mortality of corals in the El Niño of 1998 is perhaps more of a threat to continued reef development than mortality to corals alive at the time of the tsunami. Mortality of the many ‘branching’ and small ‘massive’ corals in 1998 produced a large amount of loosely consolidated rubble that has been eroding since then, creating mobile rubble fields not conducive to new coral settlement and survival. Over the years, however, these rubble fields and branching frameworks have slowly consolidated into a loosely packed matrix, becoming more suitable for new reef growth. However, this reef matrix was not robust enough to resist the tsunami waves, in terms of either the force of water or collisions with mobile rubble and rocks. Thus, in these situations, the tsunami not only destroyed all the framework-consolidation that had

Seychelles

Tsunami impacts on coral reefs and sea grass beds



Key populated areas

- Victoria - national capital
- Settlements

Natural features

- Coral reefs
- Reclaimed lands
- Protected areas
- ~ Rivers, lakes and lagoons

Impacts on coral reefs and sea grass

- Fringing reefs located predominantly on carbonate substrates and affected by tsunami through wave surge, backwash, substrate movement and sedimentation
- Sea grass areas affected by smothering

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UNEP/GRID-ARENDAI - 2005

Sources: Seychelles Ministry of Environment 2005, UNEP Seychelles Assessment Team 2005, IUCN 2005

occurred since 1998, but also mobilized older unconsolidated framework. This type of damage is longer term and more serious than simple damage or mortality to live corals on a hard substrate, which could eventually re-grow or support recruitment of new corals. The now highly mobile reef/rubble frameworks of the outer Seychelles islands have made reef survival and recovery more sensitive to impact from storm surges and pose a greater challenge to recovery and restoration than would dead corals on hard rock.

It is expected that little direct damage from the tsunami would have been sustained by any of the coral reef habitats in the central, south and western parts of the granitic islands, and all outer islands sheltered by the Seychelles bank (e.g. the Almirantes, Aldabra and others). It is likely that some damage was sustained in the eastern outer islands which are closest to the tsunami origin and unprotected by the shallow waters of the Seychelles bank.

Given the importance of coral reefs to the economy, society and infrastructure of Seychelles – all the damaged northern sites are prime tourist locations for the country and the most highly damaged terrestrial locations are adjacent to degraded reef areas – this constitutes a significant economic threat to the country and requires action.

Damage to sea-grass beds was noted at only one location, in Baie Ternaie Marine Park, Mahé. In this case, a sea-grass bed adjacent to a drainage channel in the reef was smothered by sediment, probably mobilized from the extensive shallows and reef-flat area, and backwash from land. Deposition occurred as sediment was being transported offshore by strong currents.



Eroded turtle beach at Anse Kerlan, Praslin. Credit: M. de Vries

Case Study: Anse Kerlan, Praslin

Few people realize that tidal waves can turn corners. The island of Praslin was badly affected on its west coast as well as the east coast facing the incoming tsunami. The first sign along the two-kilometre stretch of Anse Kerlan (Kerlan Bay) was a massive tidal retreat as the tsunami pulled water away from the island. When the returning (refracted) waves struck, they flooded over the dunes, toppling trees, damaging houses and destroying garden crops. As they retreated, the waves dragged up to 200,000 cubic metres of sand out to sea, leaving a steep erosion cliff up to 2.5 m high in places.

Anse Kerlan, is not only a popular beach with tourists and local people, but also important for nesting hawksbill and green turtles. The erosion of the beach threatens protective vegetation, soils, housing and turtle nests. Action is essential to prevent further loss of sand in the northwest monsoon season.

Hydrodynamic studies are needed in order to recommend either building of groynes (which could affect the turtles) or replenishment of lost sand. More immediately, the authorities must restore coastal vegetation and instigate a regular monitoring programme. Training and capacity building are also essential.

Beaches and shorelines

With respect to coastal vulnerability and protection, there are two primary classes of natural coastline: steep granitic shorelines, which are highly resilient to waves, and flatter coastal plains fringed by coral reefs, which are more vulnerable. A third class of shoreline, protected by coastal reclamation, is the artificial and increasingly important shoreline around Victoria (Mahé). These basic shoreline differences had a profound effect on the impacts of the tsunami on coastal and terrestrial habitats. Impacts were nil on granitic coastlines (where the slopes exposed to ocean waves have prevented infrastructure development on the shoreline itself) and restricted to coralline and highly altered shorelines around Victoria.

The effects of the tsunami on coastal erosion are clearly visible not only on the exposed eastern side of the islands, but also on the western side, for example on the Anse Kerlan beach in northwest Praslin. The refracting tsunami waves caused beach erosion cliffs of more than 2.5 m height in places – see the Case Study above.

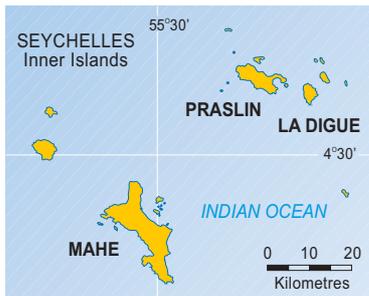
Exposed locations of the inner islands of the Seychelles are suffering from chronic coastal erosion caused by wave impacts of tropical depressions. Coastal erosion is considered a major problem where people are living close to the shoreline, as in the Anse Kerlan area and 25 other erosion hotspots. Coastal sand and coral mining in the Seychelles in the 1980s and 1990s also enhanced coastal erosion. However, these practices are now greatly reduced due to the enforcement of the Removal of Sand and Gravel Act (1991) and the Environment Protection Act (1994). The map on page 28 shows the erosion-sensitive areas of the two main islands of Mahé and Praslin.

Impacts on marine turtle nesting beaches

The Seychelles provide critical habitat for marine turtles. Significant populations of green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) turtles commonly use beaches for nesting. Sea-turtle nesting sites are located on many of the beaches around the inner Seychelles islands. As such, they are vulnerable to erosion of the upper beach, as described above. The peak nesting season for hawksbill turtles is December to February. Fortunately the highly eroded beaches (e.g. Anse Kerlan, Anse Royal) were not crucial as nesting sites, and direct exposure of turtle eggs was only reported for two nests from Curieuse Marine Park. Turtle monitoring programmes from other islands, including Aldabra, Farquhar, D'Arros, St Joseph, Bird and Aride islands indicated no known damage. Long-term impacts on nesting activity may be significant, however, and need to be monitored.

Seychelles

Shoreline vulnerability and tsunami impacts



Key populated areas

- Victoria - national capital
- Settlements

Natural features

- Coral reefs
- Reclaimed lands
- Protected areas
- ~ Rivers, lakes and lagoons

Shoreline erosion and coastal impacts

- Beaches regularly affected by erosion
- ~ Coastal erosion and scarps caused by tsunami wave surge and backwash
- Damage to coastal vegetation and infrastructure of the protected areas
- Impacts on marine turtle nesting sites and tortoise pens (artificial cages)

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Sources: Seychelles Ministry of Environment 2005, UNEP Seychelles Assessment Team 2005

At Anse Cimetiere, Curieuse, high levels of beach erosion are normal at this time of year. In Curieuse Marine Park at least two hawksbill turtle nests were flooded and eggs exposed, and although a number of these eggs were recovered and reburied by MPA rangers, such incidents may have occurred on other beaches where MPA staff were not present.

Mangroves and coastal vegetation

The tsunami caused widespread impacts on coastal vegetation. A distinction in impacts should be made between beach-crest vegetation and mangroves. At present, the mangrove area is limited to small patches within the coastal zone. Nine mangrove species have been recorded for the Seychelles. The Marine National Park of Port Launay on Mahé Island and Curieuse Marine National Park are the best-developed areas. Behind new land reclamation in front of Victoria, Mahé, a new mangrove swamp has been planted and has developed well.

The main direct impact of the tsunami on the mangroves was the deposition of sand and silt, which may have covered the aerial roots (pneumatophores) in places. Patterns of water circulation through the mangroves will also have changed due to scouring of new channels and blocking of others. While no significant short-term effects were observed, monitoring of the mangrove ecosystem would provide a clearer picture. Of major concern is the altered hydrodynamic environment in Curieuse Marine Park. Here, intensified circulation and wave exposure, caused by damage to the causeway, may threaten the mangroves. Short-term intervention may be required, subject to a careful cost-benefit analysis.

Beach-crest and coastal vegetation borders practically all soft shores of the Seychelles. Much of it has been planted artificially and is a mix of indigenous and alien species. Vegetation has been visibly impacted at many locations. The severity of the impact is increased in situations where the fringing beach and foreshore are narrow, either naturally or due to previous erosion. The tsunami impacts consist mostly of uprooted plants at the beach crest or exposed root systems. As most beach-crest and coastal vegetation is salt tolerant, long-term impacts are not expected. It is clear that the role of beach-crest and coastal vegetation was very important in reducing the impact of the tsunami wave, due to its role in sediment stabilization, sand trapping and wave attenuation. The maintenance



Tortoise on Curieuse island.
Credit: M. de Vries



Mangrove patch in Curieuse National Marine Park.
Credit: M. de Vries

and extension of areas of mangroves and coastal vegetation is of importance for reducing the vulnerability of the coastal zone to erosion and the impacts of severe storms and tidal surges.

Estuaries and wetlands

Wetlands are scarce in the Seychelles and, where they do occur, perform important functions in water storage and safeguarding of biodiversity. Estuaries and freshwater wetlands are limited in area, due to the generally steep topography and therefore limited extent of the coastal plains. Many wetland areas have been gradually lost as a result of conversion for agriculture or through drainage/infilling for infrastructure development. Non-mangrove wetlands in the coastal plains have been directly hit by the tsunami, causing salinization of surface-water and groundwater. The heavy rains that followed the tsunami probably flushed a considerable amount of salt out of these systems. Immediate impacts on vegetation can be seen in the yellowing or shedding of leaves of herbs, shrubs and trees. Long-term impacts are not expected due to naturally intensive flushing of these systems with fresh water.

Surface and groundwater

All the islands in Seychelles rely on surface water. Groundwater is only used to augment water supply during the dry seasons on La Digue. The impact of the tsunami on groundwater has not been assessed. However, the Crop Development and Promotions Division of the Ministry of Environment and Natural Resources reported saline intrusion into groundwater in coastal areas, just after the tsunami and before the torrential rains that followed.

Soils and agriculture

The salt water that flooded low-lying coastal areas undoubtedly washed away soil and nutrients and increased the salt content of the soil. The subsequent torrential rainfall would have leached much of the salt from the soil, though parts of Victoria continued to record high salt levels of approximately double the tolerance threshold of most plants in the Seychelles. Sodium also breaks down soil clods, thereby promoting soil capping and reducing infiltration rates. This might have contributed to flooding in the coastal areas caused by the torrential rains that fell the day after the tsunami.

Many ornamental plants and food crops were affected either by the force of the seawater surge itself, by exposure to saline water, or by seepage of water through the soil. Ornamental palms in Victoria, including those previously believed to be salt tolerant, died and had to be replaced. Leguminous trees and herbaceous trees died immediately.

Though the tsunami caused significant damage to some farms (the impacts on eight farms was estimated at approximately USD70,000), the effect of the torrential rains which followed was even more widespread.

Fisheries

Fish supply in the markets was low during the weeks following the tsunami. However, this was due to damage to the fishing fleet, and no reports of reduced fishery productivity have been received.

2.4 Influence of marine/coastal and terrestrial ecosystems on vulnerability of the coastal zone

The importance of the coral reefs and their structure is shown by the locations of major terrestrial and coastline damage, and the influence of these marine ecosystems on shoreline vulnerability. The major locations of terrestrial damage, at Anse Royale and Anse la Mouche on Mahé and to the sea wall in Curieuse Marine Park, are located on coastlines with fringing reefs. Significantly, shoreline damage was focused where deep channels lead through or up to the fringing reefs, focusing and amplifying the wave energy to these points. Thus two of the primary assets of the fringing reefs – the combined shelter and ocean access that have allowed coastal development just above the high tide line – were also the primary factors that increased vulnerability of some areas to the tsunami (and therefore also to other wave, tide and storm-related threats). The risk will intensify with climate change, due to rising sea level and intensified storminess, and the patterns shown by tsunami damage should be used as indicators of future vulnerability.

The coastal protection function of the vulnerable coralline coastlines of the granitic islands is further threatened by the long-term degradation of coral reefs, which results in erosion of the reef crests and the passage of larger waves. If degradation is allowed to proceed unchecked, through pollution, overfishing and coral-bleaching, their protective function will be eroded, and the adjacent shorelines will become increasingly vulnerable to wave impacts, which will be increasingly exacerbated by sea-level rise.

In the same way, coastal vegetation (see above section on ‘Mangroves and coastal vegetation’) has significantly helped in stabilizing shores and reducing the impact of the tsunami. Management and extension is seen as a priority short-term activity to reduce coastal zone vulnerability.

Most of the Seychelles islands are still under some form of forest cover. The forests were generally not affected by the tsunami as they are mostly located on mountain slopes. However, forest cover is adversely affected by forest

fires, rockfalls and torrential rains. Some landslides and rock fall caused by running water have opened up large gaps in the forest canopy. This has led to large volumes of sediments and debris being transported into the marine ecosystems during periods of intensive rainfall. In turn, this can cause smothering of mangroves and wetland vegetation in the coastal plains. Furthermore, the deposition of debris and sediments on coral reefs can have a negative effect on a marine ecosystem already degraded by the 1998 coral bleaching event.

2.5 Impacts on marine and terrestrial protected areas

At present, marine parks occupy about 10% of the area of the continental shelf, generally occupying the nearshore areas of the islands. The principal impacts of the tsunami on marine ecosystems occurred within marine protected areas. Sites in Baie Ternaie Marine Park, Anse Cemitiere in the St Anne Marine Park (Mahé) and Curieuse Marine Park suffered the highest degree of damage from wave impacts and subsequent silt deposition on the reefs and sea-grass beds. Inshore and terrestrial protected areas such as the Ramsar site at Port Laumay were not significantly affected.

2.6 Secondary environmental impacts resulting from damage to infrastructure

Over 90% of the Seychelles population lives on the granitic islands of Mahé and Praslin. There are two distinct zones on these islands: the hillsides and the coastal plain. Most development, such as industry, hotels, schools and houses, is located on the coastal plains. The government policy of discouraging development on hillsides because of erosion and resulting landslides, will increase the pressure for infrastructure in the coastal zone, which is also very vulnerable to tsunamis and other tidal waves. Artificial islands have been built at Victoria to help relieve this pressure.

Industrial sites, power plants and ports

The damage sustained by port infrastructure was mostly concentrated in Victoria. Two sea walls collapsed, five quays developed wide cracks and the internal fittings of some fish-processing factories were damaged as a result of the massive waves. Apart from rubble, there were no reports of any contaminants released into the environment. Any waste generated was disposed of within the normal waste disposal stream. For instance, 24 tons of contaminated fish at Oceana Fisheries was used to prepare stock feed, in line with the country's waste management practice.

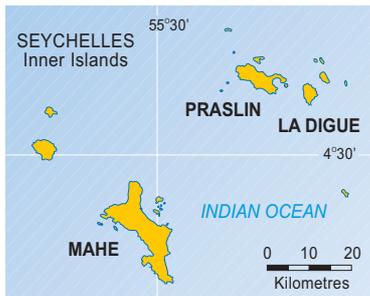
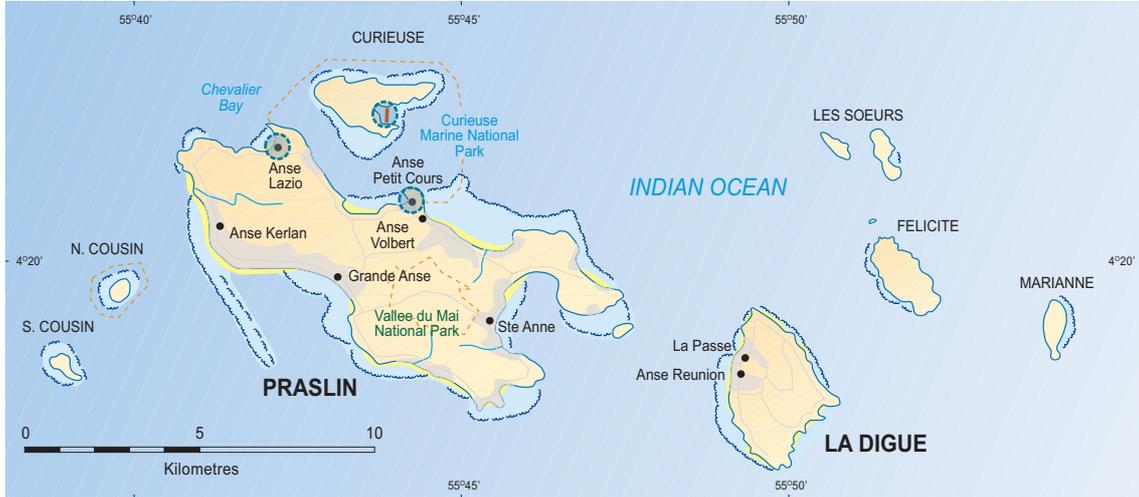
Sewage, debris and solid wastes

The breakage of pipes and subsequent discharge of raw sewage into some marshes and the Victoria lagoon over a period of ten days was the biggest water pollution incident. The violent and sudden reversal of the waves and backwash caused the collapse of the Roche Caiman Bridge. This bridge provides support to the 500 mm-diameter sewer conveying sewage from Victoria to the treatment works at Provident. As a result, the sewer broke and spilt raw sewage into the lagoon. Another 150 mm sewer rising main from Roche Camain Stage II was also affected. Because sewage could no longer be pumped to the treatment works, raw sewage also overflowed at the pumping stations. The effect of the discharge was not assessed as the high dilution factor in the lagoons is believed to have lessened the adverse impact on the environment. Because the sewer requires the support of the bridge, it could only be repaired after the bridge had been rebuilt. This took ten days during which residents were informed of the threat and advised to take basic hygiene precautions.

The collapse of another bridge, at Anse la Mouche, and that of the Roche Caiman Bridge broke water supply pipes which convey water from a desalination plant to Hermitage reservoir and to the East Coast Reclamation Area. The outer islands (Cerf, Round, Long, Moyenne and St Anne) are all provided with water from the east coast of Mahé through a submarine pipe. The tsunami caused the submarine pipe to move laterally, causing abrasion and rupturing of the pipe. The Public Utility Corporation provided a temporary connection for the water supply. The cost of repairing the water and sewer is estimated at approximately USD91,000.

Seychelles

Tsunami impacts on infrastructure and human environment



Populated areas and dump sites

- Victoria - national capital
- Settlements
- Developed areas
- Dump sites

Natural features

- Coral reefs
- Reclaimed lands
- Protected areas
- Rivers, lakes and lagoons
- High sensibility of the marine environment

Infrastructure affected

- Structural damage to buildings and port facilities, debris washed onshore
- Localized faecal pollution caused by the destruction of sewage pipeline
- Destroyed bridges and road washouts
- Damaged under sea drinking water pipeline
- Heavy rainfall 28-30 Dec 2004 in the north of Mahe, totalling 300-450 mm in 3 days. Impacts on roads, settlements, agriculture.

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Sources: Seychelles Ministry of Environment 2005, Seychelles Meteorological Service 2005, UNEP Seychelles Assessment Team 2005



The remains of a road swept away by the tsunami (photo taken from repaired section). Credit: M. de Vries

The solid wastes generated as a result of the tsunami were mostly debris from damaged infrastructure. Most of the damage came from Mahé and Praslin islands and to a lesser extent La Digue. In residential areas along the coast, the tsunami caused extensive structural damage to five schools, about 100 houses, sports facilities, rock armouring, sea walls and five bridges. This generated 296 tons of debris which cost USD15,350 to dispose of.

Surface runoff

The incoming waves swept debris and sand into drains. This blocked the system which carries floodwater from inland areas. Seychelles has a chronic erosion problem which causes frequent landslides in steeply sloping areas. As the tsunami was closely followed by torrential rainfall, the blocked drains and the high silt load from the hillside resulted in major flooding of the coastal plains. A total of 8,947 m of pipes needed desilting at a cost of USD149,000.

2.7 Increasing chronic risk from natural hazards

The impacts described above must be considered against the context of a generally rising level of risk from natural hazards.³ The UNEP team met with the National Disaster Committee of the President's Office and was appraised of the range of natural hazards that appear to be affecting the Seychelles more frequently. Over the last 40 years major events in addition to the 2004 tsunami have included fires, storms, floods, landslides and severe drought:

- tropical storms and cyclones have become more frequent, the most recent event being a devastating storm in September 2002. There is growing evidence that changing global weather patterns are bringing Seychelles within the cyclone belt. As detailed above, the tsunami was followed by torrential rains which caused landslides, and tree/rock falls;
- in late 2000 and early 2001 a major drought affected the Seychelles, requiring emergency water tanker supplies in Mahé for several weeks. Economic losses amounted to hundreds of thousands of US dollars;
- rockfalls are of wide public concern and the 1996 Sensitive Zones Atlas of Seychelles identifies six high-hazard areas in Mahé alone; and
- forest fires are a frequent occurrence, the most serious being in 1960 on Curieuse and in 1980, 1990 and 1999 on Praslin.

The anticipated effects of climate change include increased atmospheric and sea-water temperatures, a shift in the area vulnerable to cyclones and increased frequency of cyclones. Furthermore, an acceleration of global sea-level rise (ASLR) is expected and could be in the order of half a metre within one century according to the IPCC's Third Assessment Report. The impacts of ASLR will be experienced in Seychelles through increased tidal flooding, greater coastal erosion and salt-water intrusion into rivers and estuaries. Changes in rainfall regime will affect the runoff absorption and drainage capacity of the coastal zone and are likely to damage the coral-reef system through increased siltation.

While there is no reason to suppose that tsunamis will become more frequent in Seychelles, the apparent overall risk increase from 'natural hazards' means that development in the Seychelles needs to be carefully planned and controlled in line with principles of environmental sustainability in order to safeguard living conditions and to reduce vulnerability over the long term. Adoption of an ecosystem-based approach to land-use management, recognizing the critical linkages between terrestrial and marine areas and encouraging sustainable socio-economic development, would help to achieve this, but would also require development of enhanced early-warning and risk-response mechanisms. These are considered further in Chapter 3.

³ The term 'natural hazard' is used while recognizing that the underlying causes of such hazards will often be human-induced.

FINDINGS: INSTITUTIONAL CAPACITY FOR ENVIRONMEN



The tsunami destroyed the breakwater and walkway in Curieuse National Marine Park.
Credit: M. de Vries

WATER MONITORING AND MANAGEMENT



3. FINDINGS – INSTITUTIONAL CAPACITY FOR ENVIRONMENTAL MONITORING AND MANAGEMENT

3.1 The need for environmental monitoring

As described in Chapter 1, the Seychelles cover a vast oceanic region of some 1.3 million km², with a central core of granitic islands and numerous dispersed, very low-lying outer islands. The apparently increasing frequency and severity of extreme weather events and other ‘natural’ hazards place the islands at growing risk and necessitate the expansion and strengthening of environmental monitoring capacity at a national level.

As a result of global climate change, three specific risks are increasing in the Seychelles:

- the cyclone belt is widening and moving closer to the islands;
- sea-level rise is accelerating; and
- sea-surface temperatures are rising (the 1998 El Niño event has already caused catastrophic coral bleaching).

None of the symptoms of these risk factors is adequately recorded by the current monitoring capacity in the Seychelles, which was further degraded by the effects of the tsunami. Improved monitoring capacity will serve not only national interests, but will also fulfil an important international role, given that the islands straddle a broad swathe of the Indian Ocean.

Building effective monitoring capacity requires action at multiple levels, including:

- physical monitoring (sea level and tides, air and sea temperature, winds etc);
- biological monitoring (coral reefs, plankton, pelagic and fishery resources, coastal vegetation, mangroves and terrestrial flora and fauna); and
- socio-economic monitoring (vulnerability indices, water supply, resource use etc).

Additionally, strategic alliances combining government and non-governmental (NGO and private sector) monitoring initiatives need to be strengthened, especially to meet the challenge of establishing and maintaining data collection from the dispersed outer islands and extensive oceanic areas. Developing sustainable capacity for monitoring that is largely self-sufficient is critical to the long-term integrity of the system. Of critical importance is the role of the Marine Parks Authority in monitoring the health of marine ecosystems as indicators of the general status of the islands. A robust monitoring system will help to inform decisions in the sustainable management of these ecosystems as important protective barriers and economic resources.

The tsunami damaged the Meteorological Service’s tidal gauge station, located close to the International Airport. Also damaged or lost were key components of the MPA’s monitoring infrastructure, including mooring buoys and technical equipment.

The severe weather that occurred immediately after the tsunami damaged the four main Meteorological Stations in Mahé, the weather station in Praslin and 35 rain-gauge stations. However, these facilities were repaired within a month, using in-country know-how, underlining the importance of building national self-sufficiency in monitoring and disaster response capability from system design, through day-to-day operation, to long-term maintenance.

3.2 Rebuilding and strengthening monitoring capacity

Immediate action is needed to restore the monitoring capacity damaged by the tsunami, but moreover to significantly increase environmental monitoring capacity and application of the data gathered.



Dredging a clogged discharge channel.
Credit: M. de Vries

Tidal and sea-level gauge network

Improved capacity is needed for monitoring sea level and tides across the central granitic islands (i.e. the main centres of population), the dispersed coralline atolls to the extreme east, south and west, and open ocean locations in deep water and on the Mascarene Plateau. Training and capacity building directed at the key government institutions, the Meteorological Service, and linked in with other relevant departments and services should be included. The system should be linked-in to a developing Indian Ocean/global sea-level observation network and tsunami/storm-warning system.

Monitoring in the Marine Parks Authority

The MPA has primary responsibility for marine protected areas on the granitic islands, while a variety of private islands, NGOs and government corporations execute similar responsibilities on some of the outer coralline islands. Recommendations for restoring and enhancing the MPA's monitoring capacity should also be applied to these other institutions, to build a strong network for monitoring the marine environment, providing early warning of climate change and other threats, and to determine impacts and recovery trends. A further critical component is alliances between management bodies and scientific/research institutions to strengthen the monitoring programmes and build expertise within the Seychelles. The dual role of the MPA in this regard, combining science and management roles, can be a key model for this.

Components for rebuilding monitoring capacity in the MPA should include:

- equipment for physical monitoring, in particular of sea-surface temperature, and other variables such as nutrient parameters, tides, weather data etc, requiring effective partnerships with the Meteorological Service and other relevant government bodies;
- structures, strategies and equipment for embedding the data generated by the monitoring programme in MPA management decisions;

- equipment and staff capacity for monitoring coral reefs and associated ecosystems (requiring review of the staffing levels at MPA headquarters and decentralized offices, the research needs identified by SCMRT and other institutions, the monitoring and surveillance equipment required, and field operation/maintenance costs); and
- training and capacity building in monitoring programme coordination, methodologies, communication technologies, data management, and integration with international monitoring/research networks.

Further recommendations are summarized in Annex 1, though it should be noted that the proposal for strengthening SCMRT-MPA has been progressed as an urgent priority under further consultations with IUCN and CORDIO.

3.3 Environmental framework laws

Long-term government plans for an Integrated Coastal Zone Management Strategy (ICZMS) include proposals for a comprehensive legal framework. Coastal zones are currently covered by various overlapping laws and regulations, including the Beach Control Act, covering the use of resources and different activities between high and low water mark, and the Town & Country Planning Act. The commonly applied 25-m set-back for coastal development is not currently enforced by legislation and is purely regulatory in character. However, rigid application of a 25-m set-back threshold does not provide sufficient protection for coastal areas vulnerable to tidal/storm surges and should be applied as the minimum set-back permissible, and only in areas of low sensitivity/vulnerability. The impacts of the tsunami show clearly that greater set-back distances are required in many cases. Moreover the set-back regulation should be upgraded to a law, in order to provide more effective protection to the coastal zone.

Bearing in mind the impact of actions inland on coastal ecosystems, forest management laws – now 60 or more years old – may be in need of reform to tackle the adverse environmental impacts of forestry operations and deforestation in the coastal zone.

In urban areas the 1994 Environmental Protection Act, covering waste management, pollution and sewage, appears to have served Seychelles well during the recent tsunami. Environmental impact assessment – at various levels of detail – is required for all developments,.

At the international level, Seychelles is party to the Conventions on Biological Diversity (CBD), Climate Change (UNFCCC), World Heritage, Migratory Species (CMS/Bonn Convention), International Trade in Endangered Species (CITES) and Wetlands (Ramsar Convention). A Biodiversity Act, currently under development, is foreseen as providing the enabling legislation for these conventions. International technical support in this endeavour would be highly valuable.

3.4 Coastal zone management

Solving complex, interrelated problems in the coastal zone requires a holistic vision of coastal processes, both natural as well as socio-economic. The required vertical and horizontal integration of effort will be facilitated by institutional strengthening of national, district and local authorities, applied scientists and stakeholders. A high-level, national coordinating committee for ICZM is not at present in place. Its establishment should be considered in order to improve communication between, and integrated decision-making by, relevant actors. Such a national committee for ICZM could also play an important coordinating role in tying together the challenges and management solutions for interrelated ecosystems: mountains, forests, rivers, coasts and reefs. The committee could also serve as a focal body for implementation of international conventions.

The Coastal Zone Management (CZM) Unit within the Ministry of Environment and Natural Resources is at present coordinating a limited number of activities solely related to coastal erosion and adaptive measures. The mandate of the Unit should be widened to prepare for its functioning as a technical secretariat for a future national committee

for ICZM. In order to deliver this wider mandate, the Unit should be expanded through both an increase in human resources and of their capabilities. Further recommendations are presented in Annex 1.

3.5 Early-warning and awareness raising

Efforts are needed in order to strengthen the present rather limited early-warning capacities of the Meteorological Service through:

- providing equipment for monitoring of water levels, waves and sea-surface temperatures;
- training of personnel (technical training for maintenance, and applied scientific training on data storage and analyses); and
- forging links with international meteorological organizations.

There is a need for generally increased public awareness of natural hazards facing the Seychelles. Efforts should be geared specifically towards schoolchildren but attention should also be given to improving lines of early-warning communications throughout the community.

3.6 Disaster management

The El Niño-related floods and coral bleaching which struck the Seychelles in the late 1990s raised public and government awareness about the necessity of strategic disaster management. The President's Office revitalized the National Disaster Management Committee, which was asked to prepare a National Disaster Response Plan (NDRP). The Ministry of Environment and Natural Resources was given the lead. In September 2002 a strong tropical storm caused major damage to the environment and tourism, prompting the Ministry to request additional capacity from UNEP and the UN Office for Coordination of Humanitarian Affairs (OCHA). The results of the joint UNEP/OCHA Seychelles assessment (March 2003) highlighted the need to finalize and implement the NDRP drafted a few years previously. In 2004 a second UNEP mission to Seychelles was asked by the Office of the President to focus on preparation of a National Strategy for Risk and Disaster Management.

Turning to the question of capacity for disaster management, in October 2004 Seychelles created a National Disaster Secretariat under the management of the Director for Risk and Disaster Management. The Secretariat acts as the operational arm of the National Disaster Committee, but as yet has no additional staff, nor basic equipment for operations. There is a serious need for capacity building to include the following:

- training in disaster management and preparedness;
- computer and communications equipment suitable for use in disasters; and
- cameras, databases and other monitoring and recording equipment.

Corresponding recommendations and approximate cost estimates are provided in Annex 1.

3.7 Utilizing local knowledge

The limited field assessments carried out by the UNEP team revealed little evidence of local/traditional techniques for coastal zone management, but this aspect is worthy of closer investigation. In certain areas, such as Anse Royale, coconut-leaf walls are constructed to protect the coast. In other areas of the western Indian Ocean, coconut fibre, mangrove stakes, stone walls and sandbags have also been used locally and to good effect.

In the outer islands of the Seychelles, local people and organizations should be more involved in monitoring and early-warning programmes, using improved means of communication.

CONCLUSIONS AND RECOMMENDATIONS



Land reclamation for housing, harbour and industrial development at Victoria.
Credit: M. de Vries



4. CONCLUSIONS AND RECOMMENDATIONS

4.1 General conclusions

The tsunami damage in the Seychelles is extensive; the response of authorities has been speedy and thorough, in this way limiting secondary impacts. It is especially relevant to mention the inherent limitations of the islands' human, technical and financial resources. Government disaster management programmes have shown resilience during the tsunami but were stretched to the limit of local operational capabilities. Sound waste management limited the load of waste and pollution reaching the sea.

It is clear that the role of beach-crest and coastal vegetation was very important in reducing the impact of the tsunami wave, due to its role in sediment stabilization, sand trapping and wave attenuation. The maintenance and expansion of mangroves and coastal vegetation is of importance for reducing the vulnerability of the coastal zone to erosion and impacts of severe storms and tidal surges.

The damage caused by the tsunami and the severe rainfall of December 2004 must be seen in the context of increasing frequency over recent decades of impacts from other natural hazards, including fires, landslides, storms, drought, rising sea level and rising ocean temperatures. These threaten the functioning of the marine and terrestrial ecosystems which are the lifeblood of the Seychelles economy and of worldwide importance.

The tsunami event of December 2004 should be used as a trigger for rethinking and recalibrating the present management of the Seychelles coastal zone. Recognizing the tsunami as one of many actual and potential natural and human-induced hazards will help the islands to cope better with future threats. It is therefore recommended that a long-term plan be developed, building on existing initiatives, and based on recognition of the continuous links between terrestrial and marine ecosystems. This should aim to restore the health and resilience of terrestrial and marine ecosystems, and especially the linkages between them, as a means of maintaining the sustainable functioning of the coastal zone, including the socio-economic activities it supports.

Implementation of this plan should draw on Integrated Coastal Zone Management and be underpinned by a comprehensive programme of capacity building to enhance the self-sufficiency of the Seychelles in coastal zone and marine protected area management, as well as in environmental monitoring and risk/disaster management.

International cooperation and assistance is needed to support the Ministry of Environment of the Seychelles. This necessitates cooperation, among others, between governments, scientific, research and educational institutions, the private sector and NGOs.

Seychelles has the potential to become a model example for other SIDS, as well as for neighbouring Indian Ocean littoral states, in sustainable management of the coastal zone, including risk and disaster management.

4.2 Recommendations

Short-term actions (starting 2005)

In the short term UNEP recommends the following actions to support the implementation of enhanced early-warning, assessment and monitoring capacity, together with urgent measures to repair environmental damage. More detailed next steps can be found in Annex I.

1. Assess and repair as appropriate the damage to Curieuse Island causeway.
2. Replace/repair lost and damaged MPA mooring buoys, patrolling and monitoring equipment, in order to restore basic environmental and tourism infrastructure.

3. Provisionally mitigate beach erosion and repair damage to protective infrastructure in the coastal zone using 'soft' solutions such as beach nourishment wherever possible.
4. Intensify monitoring of beach profiles in selected erosion-prone locations.
5. Strengthen nearshore marine habitat mapping to delimit impacted areas and to monitor rates of recover; and integrate onshore damage and marine habitat information to assess the spatial relationship between shoreline damage and location of protective ecosystems.
6. Reiterate and strictly apply existing rules on set-back lines for coastal zone development, in order to avoid further degrading the resilience of the coastline.
7. Identify areas vulnerable to soil erosion. Undertake efforts to stabilize hillsides and to maintain forest cover in order to reduce loss of topsoil and the impact of silt on coastal ecosystems.

Medium-term actions (2006–2008)

8. Implement capacity-building programmes in order to reach self-sufficiency in coping with hazards and managing the natural ecosystems of the islands.
9. Strengthen exchange of knowledge and management experience between SIDS and states bordering the Indian Ocean.
10. Develop and start implementing Integrated Coastal Zone Management Plans for each island, taking into account dynamic coastal processes, coastal ecosystems and location of uses in the coastal zone, linking marine and terrestrial ecosystems (including steep hillsides), through integrating ICZM and MPA management plans.
11. Develop improved flood management, including implementation of ecologically sustainable wetland management, enhance water storage and reduce flooding, in combination with forest and hillside land-use management to reduce sedimentation.
12. Develop and implement long-term environmental monitoring programmes (see Chapter 3).
13. Prepare detailed assessments of coastline stability and vulnerability.
14. Strengthen capability for early warning of marine hazards (see Chapter 3).

Long-term actions (2008–2015)

15. Develop a national policy for early-warning and disaster management that incorporates cross-cutting roles for government agencies and collaboration with the private sector, and which leads to a reduction in vulnerability of the national economy and coastal communities.
16. Develop a national policy for marine protected areas and ICZM that recognizes the protective function of coral reefs and maximizes their protection and conservation in the long term.

ANNEXES



A reconstructed bridge on the airport highway following the tsunami.
Credit: M. Collins



ANNEX I. NEXT STEPS

UNEP proposes prioritizing actions under the following four Focal Areas. Table 3 provides a preliminary indicative budget.

Focal Area 1 – Implement immediate repairs, short-term, starting 2005

In this area of action all activities listed in the short-term recommendations are reportedly being executed.

Focal Area 2 – Design and implement capacity-building programmes for government and government-related institutions, mid-term, starting 2006

Coping with the aftermath of the tsunami has clearly demonstrated that expertise in the area of disaster management and coastal zone management is insufficient. A balanced programme of human resources development and institution building is required, to include the following:

- develop a coral reef and environmental monitoring capacity in SCMRT-MPA, for example through bachelor-level environmental monitoring and database management courses for ten selected rangers and office staff, and training in associated technical skills such as diving and technical reporting;
- plan and implement substrate stabilization pilot projects for damaged coral reef areas, in cooperation with SCMRT-MPA;
- undertake graduate-level wetland/protected areas management courses for ten senior rangers and head office staff in Asia or Europe;
- provide bachelor-level public relations and educational skills training for ten staff members;
- facilitate graduate and post-graduate level exchange of experts (inter-university cooperation in the areas of forest management, integrated coastal zone management and marine ecosystem functioning, hydrodynamics, sediment dynamics, geophysics, chemistry, biology, and management skills) for five graduate-level staff in selected ministries;
- produce training/lecture materials for organizing dedicated courses in Seychelles (for government, government-related institutions, lecturers/teachers, students) in cooperation with organizations abroad;
- strengthen exchange of experts and experiences between SIDS and Indian Ocean littoral states in order to learn each other's experiences; and
- assess and improve current institutional organization in order to further increase coping capability and management quality.

Focal Area 3 – Assess coastal stability and vulnerability issues

Coastal erosion is considered a major problem, increasing the vulnerability of the islands' coastlines. The tsunami has aggravated the problem considerably. The mission proposes applying the newest insights in sustainable coastal defence to the Seychelles situation. In addition to physical intervention, the use of coastal vegetation and other protective marine ecosystems should be intensified to obtain a sustainable, safe, robust and attractive coast that can cater for many uses and provide habitat for many species. Anse Kerlan is selected as the starting point to address issues in an integrated fashion from the land side and simultaneously from the marine side. An analysis should be made of the validity of the Seychelles coastal set-back regulation in highly dynamic coastal areas such as Anse

Kerlan. Measures taken to address the coastal erosion problems caused by the tsunami and cyclones can broadly be categorized into three types: to protect, to retreat and to accommodate. The protect option can be structurally ‘hard’ or structurally ‘soft’. Hard protective engineering techniques such as the use of groynes, breakwaters, sea walls and revetments are sometimes unavoidable, such as in harbour areas. However, the hard structural option may give rise to accelerated erosion ‘downstream’, for example beyond a field of groynes, as observed in the northern part of Anse Kerlan. The study will consist of the following:

- analysis of physical forcing conditions (beach profiles, waves, currents);
- analysis management options, using a sand transport model, in order to determine the effectiveness of possible sand nourishment schemes in relation to the expected life span of sand nourishment activity;
- design of optimal solutions – probably consisting of a mix of hard structures, coastal vegetation and sand nourishment and maintenance, and taking into account impacts on nearshore housing and use of beaches by tourists and turtles;
- protection and enhancement of coral reef growth to sustain natural protection of the vulnerable coastal plain coastlines;
- costing and planning of implementation; and
- extension of the approach to 25 remaining erosion hotspots in the Seychelles.

Focal Area 4 – Design and implementation of early-warning systems and strengthening of disaster preparedness

The tsunami destroyed the tidal gauge stations of Mahé and these need to be replaced. Additionally, an early-warning system needs to be set up to help reduce the impact of ocean-related hazards in the future. To realize this capability, the Meteorological Service is aiming to increase its future monitoring capacity by installing four additional tidal-gauge stations: one on the densely populated island of Praslin, and three on the outer islands of Aldadox in the west, Facgatour in the south and Lozding in the east. This will create a chain of telemetric monitoring stations.

The second aim is to install four integrated sea buoys that monitor wave heights, frequency, direction and sea-surface temperature, and transmit data telemetrically to the Meteorological Service headquarters in Mahé.

The third aim is to increase the capabilities of the personnel of the Meteorological Service through training. The present service is manned by 35 people. Training should be provided as follows:

- two electronic technicians to spend three weeks at the National Institute of Coastal and Marine Management (RIKZ) of The Netherlands Ministry of Transport, Public Works and Water Management;
- two maintenance persons to spend three weeks at RIKZ; and
- two oceanographers and/or meteorologists to be trained in database management and analysis for four weeks at the laboratory of Delft Hydraulics in The Netherlands.

In addition to monitoring capability, disaster preparedness needs to be enhanced. UNEP proposes establishment of an awareness-raising programme for the general public (advertising, education) in conjunction with enhanced communication capacity of key stakeholders in order to coordinate and transmit early-warning information effectively.

Annex 1, continued

Table 3. Summary and indicative cost estimates for proposed Focal Areas of action (originally costed in Euros; conversion to USD based on 1 Euro = 1.3 USD)			
Action	Milestones	Locations	Indicative costs (USD)
Focal Area 1 – Short term, immediate repairs, starting 2005			
Repair the damage to Curieuse Island causeway	Design new causeway, repair boardwalks	Curieuse Island	20,000
Restore Marine Parks infrastructure	Restore infrastructure (excl. sea wall)	Curieuse Marine Protected Area	65,000
Mitigate tsunami damage and enhance coral reef recovery	Plan and develop mitigation trials focused on substrate stabilization	All damaged coral sites	13,000
Mitigate (provisionally) beach erosion	Fill in back beaches, restore vegetation	Most affected erosive areas	130,000
Intensify monitoring of beach profiles	Weekly monitoring during next S.E. monsoon season	Most affected erosive areas	65,000
Strengthen nearshore marine habitat mapping	Creation of habitat status map based on new baseline monitoring	Most impacted habitats in MPAs	65,000
Reiterate and strictly apply existing rules	Assess the acting legislation and train relevant staff	Main inner islands	32,500
Identify areas vulnerable to soil erosion and implement stabilizing measures	Map vulnerable areas. Start replanting schemes	Main inner islands	65,000
SUB-TOTAL			955.500
Focal area 2 – Mid-term, capacity building & implementation of ICZM, starting 2006			
Implement capacity building programmes	Assess needs and implement programmes	Government institutions and parastatals	325,000
Strengthen international exchange of knowledge and management experience	Strengthen networks that are available (SIDS)	Government institutions and parastatals	65,000
Develop and implement Integrated Coastal Zone Management Plans	Cooperate with international experts to draft and implement plans. Institutional building, quantification, awareness raising. Link to coastal erosion activity	Main islands	520,000

Annex 1, continued

Action	Milestones	Locations	Indicative costs (USD)
Develop improved drainage schemes	Analysis of drainage of coastal plain, implementation of flood reduction solutions	Islands with drainage problems	325,000
Develop and implement long-term monitoring programmes	Provide data for analysis, determine state and trends in coastal ecosystems	Key locations on all islands	325,000
Implement substrate stabilization mitigation activities, coral reef areas	Trial substrate stabilization options and implement at damaged coral reef sites	All damaged coral reef sites	260,000
SUB-TOTAL			1,820,000
Focal Area 3 – Mid-term, capacity stability issues of the coastline, starting 2006			
Address stability issues of the coastline	Analyse 25 coastal erosion hotspots, starting with Anse Kerlan. (Design and implement sustainable solutions for each site)		325,000 (26–52 million @ 0.5–1.4 million each)
SUB-TOTAL			325,000
Focal Area 4 – Mid-term, early warning systems and disaster preparedness, starting 2006			
	Two additional tidal gauge stations		91,000
	Sea buoys		195,000
	Training		104,000
	Communication & awareness raising, local knowledge		195,000
	Maintenance costs (5 years)		195,000
SUB-TOTAL			780,000
GRAND TOTAL			*3,880,500

*Excludes project management costs and also implementation of sustainable solutions at 25 coastal erosion hotspots (estimated at an additional USD26–52 million).

ANNEX 2. KEY INDIVIDUALS CONTACTED AND SITE VISITS MADE**(A) KEY INDIVIDUALS CONTACTED**

 Ministry of Environment & Natural Resources

Mr Ronny Jumeau
Minister for Environment & Natural Resources

Mr Rolph Payet
Permanent Secretary

Mrs Nadine Dulac
Technical Advisor
Pollution Control & Environment Impacts Division

Mr Cliff Gonzalves
Director
Solid Waste & Cleaning Section
Pollution Control & Environment Impacts Division

Mr Jason Jacqueline
Legal Officer
Policy Planning and Services Division

Mr Flavien Joubert
Director
Pollution Prevention & Control Section
Pollution Control & Environment Impacts Division

Mr Antoine-Marie Moustache
Director General
Crop Development & Promotion Division

Mr Joseph Francois
Director
National Parks and Forestry

Mr Alain de Comarmond
Coastal Zone Management Unit

Mr Pugazhendhi Murugaiyan
Wetland Unit

Ms Dina Bristol
Personal Assistant

 Ministry of Land Use and Habitat

Mr Francis Coeur de Lion
Director
Centre for Geographic Information Systems

 Ministry of Tourism & Transport

Mr Alone Edmond
Director General
Land Transport Division

 Ministry of Foreign Affairs

Ms Vivianne Fock-Tave
Directrice Générale
Division des Affaires Economiques Internationales

Mr Sylvestre Radegonde
Principal Secretary

 SCMRT-MPA

Mr Jude Bijoux
Manager

Ms Kate Pike
Research Officer

Mrs Mary Stravens
Managing Director

 Seychelles Fishing Authority

Mr Randolph J. Payet
Managing Director

 Natural Disaster Committee

Mr Wills Agricole
Director
Seychelles National Meteorological Services
Policy Planning & Services Division
Ministry of Environment & Natural Resources

Mr Alone Edmond
(see under Ministry of Tourism & Transport)

Mrs Françoise Shroff
Principal Secretary
President's Office

Mr Andre Valmont
Central Police Station

Mr Michel Vielle
Director General for Risk and Disaster Management
National Disaster Secretariat
President's Office

Mr Nirmal J. Shah
Managing Director
Nature Seychelles
Bird Sanctuary
Roche Caiman

NGOs

Ms Elke Talma
Marine Conservation Society of Seychelles

(B) SITE VISITS MADE

The following list summarizes the findings from visits made by the UNEP mission team on 5 and 6 February 2005 to sites on Mahé, Praslin and Curieuse. Also included is information from additional visits to coral reefs and sea-grass beds conducted by the IUCN survey team between 1 and 8 February 2005.

1. Beau Vallon Beach, Mahé

Beach runs NE–SW, sloping steeply and fringed with Takamaka, Casuarina and Coconut trees. Minimal damage except at a gap in the tree defences where the waves broke through a 30 m gap, flooding inland and dragging back a 2 m-deep channel now refilled with coral debris. Clear circumstantial evidence of the value of mature trees in coastal defence.

2. Beau Vallon Storm Drain, Mahé

5 m-wide drain heavily silted with sand and debris to a depth of 0.75–1.0 m, requiring clearing for a length of 300–400 m. Approximately 2,000 m³ of sand driven up into the drain. Clearing by contractors using mechanical shovels; limited access. Signifies importance of regular drain maintenance in dry season.

3. Mare Anglaise, Mahé

Sea flooded over a seaside road lined to seaward by Takamaka, Bodamier (Indian Almond) and Coconut trees. Salt-tolerant species with powerful rooting systems were nevertheless undermined and perhaps damaged long term. Need for sand replacement. Essential to maintain tree defences.

4. Beau Vallon-St Louis Road, Mahé

Landslip onto roadside villa which collapsed and is uninhabitable. Steep land behind house destabilized by clearance and heavy rains following the tsunami. Government policy is to avoid migration up the slopes by providing reclaimed residential and industrial land on small islands offshore. Sites selected to minimize ecological impact to coastal and marine sites.

5. Commercial Port, Victoria, Mahé

Captains of large ships noticed very low tide and withdrew their ships offshore in advance of tsunami. Many smaller craft remained and were washed onto the Old Pier or otherwise severely damaged. Concrete block wall destroyed and major crack along pier surface, perhaps 100 m long, possibly following line of a pipe. Pier wall cracked along road edge.

6. Oceana Fisheries, Commercial Port, Mahé

Meeting with operator of a fish treatment and refrigeration plant. He had no forewarning of the tsunami and suffered significant damage to infrastructure and equipment. Factory floor flooded, causing failure of transformers and refrigeration. No personnel hurt as it was not a working day.

7. Airport Road Bridge One

The airport road runs along a spit between the sea and a marine lagoon, linked by two main channels with bridges. The tsunami flooded under the bridges and then sucked back with tremendous force. Bridge One (height about 3 m

above sea level) was destroyed, including the road and associated sewage and water pipes. Quickly replaced by the government using a temporary single channel structure that is unlikely to survive further tidal surges.

8. Airport Road Bridge Two

A much higher bridge (about 6 m above sea level) of double culvert construction, destroyed completely by backwash from the lagoon to the sea. Temporarily replaced by a stacked pipe construction using 500 mm steel pipes formerly used for land reclamation. A temporary arrangement that will not withstand further storm surges.

9. Anse Royale, Mahé

This eastern coastline is one of the two most affected districts, with extensive damage on the coast and inland from flooding. In one area, the parapets of a small road bridge over a drainage channel were swept away. Where the channel reached the sea, a large area of beach was swept away. Evidence that a straggly salt-tolerant shrub called vouloutier (*Scaveola cerecea*) growing along the beach helped to reduce erosion and other damage. The plant can be utilized in vulnerable areas.

10. Kaz Bar, Anse Royale, Mahé

A seaside bar of flimsy construction partly destroyed when seawater rose over the beach and ran inland for 100 m. Several houses to the south of this point were also completely destroyed and are uninhabitable. This was arguably the worst hit area.

11. Water Channel, Anse Royale, Mahé

Concrete and stone-built water channel draining the inland plateau and marshes, undermined by the tsunami causing collapse and cracking.

12. Catholic Church, Anse Royale, Mahé

The church itself, although very close to sea, was undamaged due to robust construction and recent renovation. Immediately south of the church the coastal vegetation, mostly Takamaka trees, were severely undermined and will need replacing. Part of road washed away, but since repaired. Additional damage to houses and walls inland of the road.

13. South of Catholic Church, Anse Royale, Mahé

Very old sea wall from 1920s, original purpose unclear. Undermined and knocked over by the tsunami.

14. Anse la Mouche, West Coast of Mahé

Beachside damage and extensive loss of citrus and other trees inland due to flooding up to 400 m inland. Red Cross distributing household goods in this area.

15. Port Launay

Rich mangrove area designated in 2004 as a Wetland of International Importance under the Ramsar Convention on Wetlands. A management plan for the site is in preparation. Very little tsunami damage; highly likely that the mangroves protected the coastline and the marshes buffered the flooding.

16. Viewpoint over East Coast, Mahé

This location clearly showed the importance of 'reclaimed' land for the future development of Mahé. Large two-year-old artificial islands with armoured walls, planted extensively with Casuarina. Will be left for five years or so for consolidation prior to building works. This will include marinas, housing developments and industrial sites.

17. Ranger Station, Baie Laraie, Ile Curieuse

The tsunami wave crashed over the beach and penetrated 200 m inland, causing flooding but little structural damage. No chemical or sewage leakage experienced. Marine park staff explained that more than 70% of Isle Curieuse coral reefs were killed by the El Niño event of 1998, but recovery had been observed since. The tsunami

was a setback to this. Ingress of Black Sea Urchins, feeding on live coral recruits increased in number, together with reduction in trigger fish populations, predators on the urchins. There are about 128 individuals of the endemic Giant Tortoise on Curieuse, censused annually.

18. Causeway, Baie Laraie, Ile Curieuse

Built in 1909 to create a 16-ha bay for rearing of turtles, this 1.5 m-high, 500 m-long curving, largely drystone causeway was severely damaged by the tsunami. The turtle-rearing project was a failure, but the causeway is said to protect and extend the large area of mangrove inshore, in which all seven Seychelles mangrove species occur. Estimated cost of repair with full concrete and granite wall is USD372,000, almost one-third of total tsunami environmental repair costs across Seychelles. Requires careful consideration.

19. Mangrove Walkway, Baie Laraie, Ile Curieuse

The wooden walkways through the mangroves around the turtle pond are an important attraction for tourists, helping to minimize their impact on the environment and reduce disturbance to nesting birds etc. The walkway was washed away in several places by the tsunami surge. Replacement and extension of the walkways is an important priority.

20. Doctor's House, Anse St José, Ile Curieuse

The Doctor's House, a key feature of the island, is built on a raised platform and was undamaged. The marine park barbecue area below the house was affected only by damage to small outbuildings.

21. Leper Houses and Staff House, Anse St José, Ile Curieuse

Ruins of 19th century leper houses unaffected, but a staff house built in the same style about 30 m from the beach was flooded, doors and windows shattered and all contents ruined.

22. Snorkel dive in Anse St José, Ile Curieuse

A 30-minute snorkelling dive in front of the Doctor's House on the western coast revealed a sparse sea-grass bed with some species of *Posidonia*, small-leaved sea-grass/weeds/algae at depths of 4–7 m, while rumpled coral masses are found at shallower depths (2–3 m). Only a few healthy coral specimens were found here, covering not more than 1% of the area.

23. Anse Kerlan, Praslin Island

Anse Kerlan in the northwest was the most vulnerable part of Praslin Island and the tsunami affected the coastline severely. Local people said the tsunami drove a wave front with a height of more than 5 m many hundreds of metres inland. People were not warned and ran for their lives to the lower slopes of the mountains behind. Many more locations on Praslin Island were also damaged by the tsunami. Parts of the coast have suffered severe erosion for at least 30 years, causing relocation of roads and houses and threatening turtle nesting sites. The tsunami aggravated this trend. Many properties are close to the edge of the beach. Attempts to protect the beach with groynes over a period of ten years have not been fully effective. North of the groynes, erosion has intensified. This part of the coast is now in need of a more structured, integrated approach. A length of more than 7 km is in need of a mix of 'soft', sand-nourishment and 'hard' coastal protection schemes in combination with zonation of the coastal area. Design of these solutions needs access to good data on sediment transport during the two monsoon seasons. For this to be successful, data on currents and waves are imperative.

24. Baie Ternaie, Mahé Island

The coral reef of Baie Ternaie Marine Park, on the northwest tip of Mahé Island, was among the most damaged sites in the islands, with more than 10% of vulnerable branching corals broken by the waves. However the high reef crest and shallow lagoon protected the shoreline from extensive damage. Channeling of water from the receding waves resulted in the burial and smothering of a sea-grass bed. In comparison with the long-term damage to coral reefs caused by coastal development over the years, and coral bleaching during the El Niño event of 1998, damage due to the tsunami event has been minor.

25. Anse Royale and Pointe Police, Mahé Island

The reef at Anse Royale is a coralline platform dominated by algae owing to its high exposure to waves from the east and long-term degradation from coastal land use. Tsunami damage was limited to the shallowest 50 cm at the reef crest where scars on the framework show where rocks (or perhaps corals) were ripped off. Pointe Police is a granite boulder field with abundant small corals at the southernmost point of Mahé. There was no evidence of damage between the surface and 10 m depth.

26. Anse la Mouche/Anse Copre, Mahé Island

Coral reefs in Anse la Mouche are characteristic fringing patch reefs, dominated by opportunistic corals on eroding substrates in the shallows, and deeper reefs dominated by massive corals. The area is impacted by eutrophication from land and overfishing, with large sea urchin populations. On the deeper reefs, below 5 m, staghorn *Acropora* coral heads were broken by the waves. In the shallows, large massive corals were toppled as their bases are highly bio-eroded, but small branching corals were undamaged. In both cases, however, damage was low at less than 5%. It was the team's impression that a layer of sand had been removed from the reef through mobilization by the waves – extensive fine rubble fields were visible in the channels between coral heads, which usually would appear as sand channels. It is possible that the removal of sand exposed previously covered layers of detrital rubble and reef framework.

27. Anse Cimetiere, Ste. Anne Island

Damage to coral reefs was highest at Anse Cimetiere, with at least 27% of colonies surveyed showing signs of physical and mechanical damage. The damage to this site has been underestimated as most of the coral colonies that were affected were completely destroyed and therefore were not included in the sampling methodology employed by SCMRT. However, historical data for this site show that the reef slope experienced an 80% reduction of coral cover as a result of the tsunami (SCMRT). The high level of damage experienced at Anse Cimetiere was due to loosely consolidated reef matrix which led to a large amount of reef rubble and structure available to be moved by the action of the waves.

28. Curieuse Island – Coral Gardens, Grande Anse and Baie Launay

Overall, 8% of coral colonies showed signs of tsunami damage (SCMRT data). There was significant damage in one area of the Coral Gardens where massive corals were overturned and exposed. This was due to the loose rubble substrate and weak structural base of these corals at this site. Many live coral colonies (Organ Pipe coral, *Acropora*, and *Pocillopora*) were washed up on the beach. Other damage included broken *Acropora* stands in Resort Bay, loosened rubble on Grande Anse and damaged turtle nests.

29. St Pierre

The St Pierre rocks are semi-sheltered between Curieuse and Praslin. They comprise exposed granite rocks on their seaward side and an extensive development of mostly dead carbonate framework in the shallows and in the lee of the islands. Corals on granite substrates showed little damage. However, the reef frameworks of dead staghorn *Acropora* corals exhibited near-total devastation. This is a key snorkelling site in Curieuse Marine Park and is a significant loss to the park. Corals close to the bottom on granitic surfaces showed evidence of breakage, probably due to rubble movement along the bottom.

30. La Reserve/Anse Petit Cours, Praslin Island

Anse Petit Cours is west-facing and sheltered by Curieuse. The shoreline and hotel suffered extensive damage from the tsunami, and this reef area suffered some of the lowest mortality of corals during 1998. Coral diversity was observed to be higher than at other locations visited. Extensive rubble damage was found in the shallows, and because of the higher abundance and diversity of corals, higher levels of breakage of live coral were recorded. In particular, flattened areas of staghorn *Acropora* were common. Because of the sloping sand base, many *Porites* colonies in waters deeper than 6 m were toppled, due most likely to erosion of sand from under one side and tumbling of the colony/boulder.

31. La Digue

The fringing reef on the western shore of La Digue and the granite outcrop at the northern tip were surveyed. As in other locations, the predominantly carbonate framework of the western shore showed extensive damage and rubble. Corals on granite rocks on the northern tip showed little damage.

32. Felicite

The patch reef on the northwestern point of Felicite was surveyed and a high degree of impact recorded, including damage to the reef substrate and overturned boulder corals.

33. Isle Coco

The coral reef at Isle Coco, which faced directly into the path of the oncoming tsunami, was the easternmost reef surveyed. It has a similar morphology to St Pierre (see site number 29). Corals on granite substrates showed little damage. However the reef frameworks of dead staghorn *Acropora* corals exhibited near-total devastation. Signs of damage included mobile rubble pieces and broken coral fragments, the accumulation of large amounts of carbonate rubble in drifts up the sides of granite boulders and, in depressions, loose dead *Acropora* tables (their large surface area making them vulnerable to movement) and craters/depressions in the branching framework where back and forth movement of such pieces by the waves caused erosion of circular depressions. There were also erosion gullies through the framework where large sections of rubble framework may have been transported to deeper water.

ACRONYMS

ASLR	acceleration of global sea-level rise
CORDIO	Coral Reef Degradation in the Indian Ocean Programme
CZM	Coastal Zone Management
GIS	Geographical Information System
GPA	UNEP's Global Programme of Action for the Protection of the Marine Environment from Land-based Activities.
ICZM	Integrated Coastal Zone Management
ICZMS	Integrated Coastal Zone Management Strategy
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IUCN	The World Conservation Union
LUNGOS	Liaison Unit for NGOs of the Seychelles
MPA	Marine Parks Authority
NDRP	National Disaster Response Plan
NGO	non-governmental organization
OCHA	United Nations Office for Coordination of Humanitarian Affairs.
RIKZ	Rijkswaterstaat Rijksinstituut voor Kust en Zee
SCMRT	Seychelles Centre for Marine Research and Technology
SIDS	Small Island Developing State(s)
UNDAC	United Nations Disaster Assessment and Coordination
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

Currency conversion

As of 20 June 2005 the following approximate conversion rate applied:

1 US dollar (USD) = 5.45 Seychelles rupees (SCR)

1 SCR = 0.18 USD

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The Rapid Assessment Mission was commissioned by UNEP and UNEP-GPA in cooperation with RIKZ/Netherlands Ministry of Transport, Public Works and Water Management.

The team members wish to thank their hosts in Seychelles who worked long hours to provide information, arrange site visits and to make the team feel welcome. A listing of key individuals contacted during the mission is provided in Annex IIA, but special thanks are due to the Minister for Environment, Mr Ronny Jumeau, his Permanent Secretary Mr Rolph Payet, and the Director of National Parks and Forestry, Mr Joseph Francois, as well as to Mr Michel Vielle, Director General for Risk and Disaster Management (President's Office), Mr Alain de Comarmond, Coastal Zone Management Unit, Mr Pugazhendhi Murugaiyan, Wetland Unit and Ms Dina Bristol, Personal Assistant.

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