Assessment of Tsunami Impacts on the Marine Environment of the Seychelles

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Executive Summary

Two major patterns in coral reef damage were noted, controlled by the geographic location of each island and exposure direction of each site, and reef substrate. 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 carbonate reef substrates. By contrast, sites around Mahe showed much lower levels of impact, generally below 10%. The limited damage on Mahe is due to the shelter provided by the outer northern islands and dissipation of wave energy as the tsunami traveled over the greater distance of shallow water from the outer edge of the banks to Mahe.

Granitic reefs suffered less damage than reefs with a calcium carbonate 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 of a compact 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. However the majority of true coral reef sites in the granitic islands have a reef framework that is loosely consolidated due to mortality during the 1998 El Niño and subsequent bioerosion. This reef matrix was not robust enough to resist the tsunami waves, either from direct impact of the force of water, or movement of rubble and rocks. In these areas significant reef rubble was moved by the wave and consequently associated live coral colonies were also displaced and damaged.

Thus these preliminary assessments suggest that extensive damage was done by the tsunami to all coral reefs in northern and eastern island groups that have carbonate frameworks. It might be that this is also the case for outer atolls and islands, and surveys should be prioritized to the eastern islands closest to the tsunami origin, and not protected by the shallow waters of the Seychelles bank. Little direct damage from the tsunami is expected for all coral reef habitats in the central, south and western parts of the granitic islands, and all outer islands sheltered by the Mascarene plateau and Seychelles bank (e.g. the Amirantes, Aldabra and others). In these areas, some damage is possible for shallow corals on carbonate substrates, but little damage is expected for all deeper habitats and all sites with granitic substrate.

Comparing these two patterns numerically, these surveys documented > 50% of substrate damage and >25% of direct damage to corals in northern and eastern-facing carbonate framework sites), <10% damage in shallow carbonate substrate sites in central, western and southern locations, and < 1% damage on all granitic substrate sites. Given the importance of coral reefs to the economy, society and infrastructure of the Seychelles (all the damaged northern sites are prime tourist locations for the country, the most highly damaged terrestrial locations are adjacent to degraded reef areas) this provides a strong threat to the country and requires action for mitigation.

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Introduction

Background

The Seychelles comprises 115 islands covering a land area of 455 km^2 in the western Indian Ocean, between 4 and 11^{o}S. Forty-one islands comprise the inner granitic group of mountainous islands, within a radius of 50 km from the main island Mahe, with Mahe, Praslin and La Digue being the largest and most important for towns and settlement. The outer islands are all coralline and built of old reef carbonate growth, and rise to only a few meters above sea level.

The tsunami

The tsunami wave that hit the Seychelles islands on 26 December 2004 had traveled approximately 5000 km from the epicenter, offshore Sumatra, in less than seven hours. At 13.00 hours tidal waves ranging from 2.5m to 4m in height hit the east coast of Praslin, La Digue and Mahé islands. The effects were felt all along the east coast of Mahé, propagating over a 30 minute period. Refracted waves hit the west coast of Praslin and Mahé 30 minutes to 1 hour after the respective east coasts were hit. Another wave occurred at 17.00 hours, followed by two smaller waves at 22.00 hours and 05.00 hours (27 December). The second wave had more or less the same effect as the first because, although smaller, it occurred at high tide. The two smaller waves caused damage only on the west coast of Praslin. The sea water surges caused by the waves flooded the low lying areas of Mahé, Praslin and La Digue and caused widespread damage to beaches, coastal vegetation, roads, bridges, other infrastructure and houses. The flooding continued for a period of about 6 hours. Two people lost their lives.

The tsunami was followed on 27 December 2004 by extreme weather with rainfall reaching 250 mm in the northern and central areas of Mahé. Torrential rains continued for several days. Runoff from the hills formed virtual rivers that swept across the country, causing widespread landslides, tree and rock fall in the northern and central part of Mahé and in other areas, with associated further damage to infrastructure, dwellings and the vegetation on slopes. The rainfall caused more widespread damage to land aras of the Seychelles, thus hampered immediate mitigation and focus on tsunami impacts. Together, these almost simultaneous incidents have caused serious damage to the infrastructure of the Seychelles.

Coastal morphology

The coastlines of the Seychelles granitic islands are of two basic types: 1) granitic coastlines where waves break directly onto granitic rock, and are often steeply sloping or accidented with large boulders and rockfalls; 2) coralline coastlines backed by coastal plains and fronted by fringing coral reefs (of either old or recent construction). On the coralline coastlines, the fringing reef crests break waves sufficiently to enable settlement and development on the coastal plains. Between the reef crest and shoreline, sheltered lagoons may be present, backed by fine sand beaches. Channels in the fringing reefs allow the passage of water in and out of the lagoons with the tides.

The flat land, calm lagoons and ocean access of the coralline shorelines have attracted settlement and development, supporting a large proportion of agriculture, urban development and tourism of the Seychelles.

Marine ecosystems and coastal vulnerability

Fringing coral reefs around the central granitic islands have allowed the development of fine sand beaches and lagoons, and settlement of the sheltered coastal plains behind them. Channels through the fringing reefs provide access to the ocean from safe harbours for artisanal fishing boats and pleasure craft. The same coral reefs provide the primary infrastructure that supports Seychelles' tourism industry, providing beaches and sites for snorkeling and SCUBA diving. Due to stresses from development and overfishing, and then the mass coral bleaching of coral reefs in the Indian Ocean in 1998 that caused 80-90% mortality of corals, many of the granitic islands' coral reefs are significantly degraded.

Impacts of tsunami waves are strongly affected by the shape and bathymetry of reefs and channels to the open sea –reef crests, complex coral reef surfaces and granitic shorelines absorb and dissipate the wave energy, while deep channels allow focusing of the waves up and closer to land. The importance of the coral reefs 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 Mouche, on Mahe, and to the seawall in Curieuse Marine Park, are located on fringing reef coastlines.

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 the combined shelter and ocean access that have allowed coastal development just above the high tide line adjacent to fringing reefs contributed to the high vulnerability of these to the tsunami. This vulnerability will also extend to other wave- and storm-related threats, and intensification of these threats through sea-level rise and changes in storm patterns.

Scope of assessment

This report aims to follow up to an initial UNEP fact-finding mission, the IUCN Global Marine Program and Coral Reef Degradation in the Indian Ocean Programme (CORDIO) were requested to prepare a more detailed assessment of the tsunami impacts on the marine environments of the Seychelles. This assessment was undertaken between February 3rd-13th, 2005 and included stakeholder consultation and site visits to eight of the inner islands of the Seychelles.

Eight inner islands and xx sites (Table) in the inner granitic islands of the Seychelles were assessed for damage that may have been caused by the tsunami, (see table x-ANNEX?? for detailed information). It was not possible in the time available to include outer atoll islands, and surveys were conducted using rapid assessment techniques thus limiting their accuracy and precision.

In geographical terms the main gap in the Mission Team's work was the focus on the inner granitic islands, to the exclusion of the coralline islands. Many such islands, for example Aldabra, are World Heritage and of global significance in terms of biodiversity. In assessing the marine environment of the inner granitic islands the main gaps were lesser known habitats, such as sandy subtidal substrates which may have been severely impacted by mixing, and the more remote island and bank reef ecosystems.

Methodology

Two survey methods were used. The first was developed as a rapid assessment tool by the SCMRT-MPA, and conducted by staff and rangers at MPA sites on Mahe, Praslin and Curieuse (SCMRT 2005 a,b,c). Four observers conducted approximately 10 minute samples, each assigned some of 7 coral taxa/groups (Acropora, other branching corals, foliose, massive, encrusting, fungids and soft corals). Colonies were recorded as damaged or undamaged (broken or overturned) along with general observations on the status of the reef. Colonies completely missing due to wave damage were not possible to differentiate using this method. Because the main coral reef areas in the Seychelles were significantly affected by high mortality in 1998 and had weak eroded frameworks at the time of the tsunami, it is likely that many coral heads were completely removed from the study sites, and thus not recorded. Surveys were conducted in 3 periods covering Mahe (30 December 2004), Curieuse (5 February) and Praslin (5 February).

The second method used was the ICRI/ISRS draft methodology for assessment of damage from the tsunami to coral reefs, developed during January 2005 (ICRI/ISRS 2005). This method recorded a broader variety of variables including damage to live corals (as the first one), and damage to the substrate and debris from the terrestrial environment. Details of the method can be obtained from the UNEP website[1] and variables recorded are explained in. The method is based on samples of $10m^2$ areas of the bottom, selected haphazardly during swims across the sample area. Surveys were conducted over a shorter period from February 7-12 by the authors of the report, in conjunction with SCRMT staff who sampled using their method (above) and undertook some training in the second method.

Results

In general, the extent of the damage caused by the tsunami will mainly depend on the slope and topography of the seabed. On gradually sloping shorelines, the energy of the wave appears to build up, sucking water away from the shore, followed by powerful flooding waves and surge transporting vast amounts of water and unconsolidated rubble. Direct damage of the tidal waves results from the massive water flows and associated kinetic energy while indirect effects include sediment deposition and land-based pollution (nutrients, pesticides, industrial and urban chemicals, biological material) brought by the backwash. Increases in turbidity and organic carbon, as a result of this pollution, may result in oxygen depletion, potentially detrimental to fish, corals and seagrasses.

Primary impacts to coral reefs

Coral reef damage in the inner Seychelles islands was limited principally to physical breakage due to the tsunami waves, surge and potentially, backwash. Damage was documented to reef substrates, mobilization of sand and rubble, and damage to live corals. Limited damage from siltation and debris was noted, and no evidence of coral diseases or other effects of pathogens or pollutants was seen. Types of damage are summarized below. The assessment focuses on damage to coral reef habitats, but also mentions associated habitats and species.

Mechanical Damage to Corals

Coral heads suffered primarily mechanical damage, which was of two main types – breakage of branches on branching species, and overturning. *Acropora* and *Pocillopora*, being the two main genera of branching corals on Seychelles' reefs were the most frequently observed to be damaged. *Pocillopora* occurs as individual heads up to 30 cm in diameter, and damage was observed as broken branches off a parent colony, and loose branches in the rubble. By the end of these surveys (on February 12, some 48 days or 7 weeks after the tsunami), most broken sections of Pocillopora had not fully healed with incomplete tissue growth over the break. *Acropora* was present as individual colonies and as fields or thickets of staghorn morphologies. The former suffered breaks similar to Pocillopora, while for the latter a field could be entirely flattened, with scattered branches in the rubble in all directions, or in a consistent direction.

Mechanical Damage to Substrate

No damage was observed on any granite substrates, nor was there any clear indication of movement of granite rocks and boulders larger than 50 cm or so. Carbonate reef substrates are weaker and less dense than granite, and showed signs of damage. In areas of hard old reef framework, damage was noted by the presence of scars where rocks and perhaps corals were torn off, but the intensity of damage was low and restricted to areas shallower than 50 cm (e.g. Anse Royale). Extensive reef degradation from the 1998 El Nino and only partial recovery of corals since then has led to most reef areas being a mix of loosely consolidated

[1] http://www.unep-wcmc.org/latenews/emergency/tsunami_ 2004/coral_ass.htm

coral skeletons and branches. Just before the tsunami, these had a varying degree of live coral attached to the reef or growing on loose rubble pieces of different sizes.

These reefs were particularly susceptible to physical damage by the tsunami waves. They showed extensive destruction depending on the local force of the wave with widespread rubble, loose rocks, overturned corals and eroded craters showing evidence of movement. Without definitive data before the tsunami it was hard to determine absolute levels of mechanical damage to substrates, however in general it appeared high, and in some cases (e.g. the northerly-exposed sites of I. Coco and St. Pierre) rubble movement and total damage may have been as high as 100%.

Movement of substrate

Movement of loose rocks and rubble was a major factor in exacerbating damage to reef substrates and to corals. Granite rocks were too dense and rounded, and showed no evidence of having been moved. Carbonate rocks were extensively moved, in all sizes from small rubble, through large dead *Acropora* tables to massive *Porites* heads over 1 m across. The low density of carbonate skeletons and the often irregular shape of rubble fragments contributed to their ease of movement by waves. In some cases, massive *Porites* heads 2 m in diameter and greater were toppled, though this was likely due to sediment movement, another form of damage described below. In some areas, such as Grand Anse, Curieuse, whole areas of the bottom looked whiter (observation by MPA ranger, Paul xx), due to the overturning of rubble revealing their whiter undersides (with darker algal growth on the upper surfaces).

Sedimentation/Siltation

The tsunami waves, compounded by heavy rainfall and rough seas in the following week, mobilized extensive amounts of marine and terrestrial sediment. Missing sediment was commonly noted in many reef habitats, where old rubble that had likely been buried in sediment for many years was exposed. These areas were visible because they lacked mature algal communities of filamentous, turf or coralline algae. At distinct reef channels, such as in Baie Ternaie, erosion of sediment from the channel edges was noted, in an extreme case amounting to an estimated 70 cm of sediment lost.

Silt deposition on rock surfaces was noted, in layers up to 2-3 mm thick on surfaces that often had a cover of thin algal filaments. However, because of the time since the tsunami waves, it is possible that more silt had built up because of subsequent factors, or some had been lost. Heavy sedimentation on a seagrass bed was also noted (see below).

Interestingly, high siltation was noted only for white carbonate silt, not darker terrigenous soil, suggesting little impact of the heavy rains following the tsunami.

Curieuse wall and mangrove forest

Extensive damage was done to the causeway/wall enclosing a shallow lagoon previously used for turtle farming, and a mangrove forest area in the Marine Park at Curieuse Island. The mangrove forest developed over the approximately 80 years that the causeway has been in place, and is one of the largest in the Seychelles, containing 7 of the 9 species found in the islands. More than one half of the wall was knocked inwards by the tsunami waves, with the principal damage occurring where a channel leads up close to the wall and from this point east to the Park HQ beach. At the time of this study, no damage had been noted to the mangrove forest, as it is sheltered from the winds of the northwest monsoon. However, a wide channel on the beach and near shore was created by the copious draining water. The southeast monsoon may start as early as April and the forest will be directly facing the wind and wave. This may lead to erosion of the leading edge of the mangroves, with consequent loss of habitat area and species. The loss of mangrove forests could have major consequences on local marine biodiversity as these areas provide habitats for many juvenile and adult crustacean and fish species. The mangrove forest is also one of the primary attractions for visitors to Curieuse Marine Park, and its loss may significantly reduce the financial income from the Marine Park, which subsidizes other protected areas that cannot support themselves.

Site damage summaries

This section provides detailed descriptions of damage observations, to be read in conjunction with the summary figures provided.

Northern islands, north-east exposure

Curieuse Island

Several sites were surveyed around Curieuse Island, in the Marine Park, including Grand Anse, Baie Launay and sites to the north and west. Overall 8.1% of coral colonies showed signs of tsunami damage and extensive rubble movements were noted on shorelines facing east, south and north. On a deeper site at 8 m east of Curieuse (Coral Gardens), many massive corals were overturned and exposed due to their eroded bases and weak framework. Many live coral colonies (*Acropora*, *Pocillopora* and *Tubipora* – organ pipe coral) were washed up on the beach. Other damage included broken *Acropora* stands in Resort bay, and damaged turtle nests (see later section).

La Digue, Felicite

Fringing reefs on the western shores of La Digue and Felicite were surveyed. As in other locations, where carbonate framework had accumulated and corals died off in 1998, extensive rubble and coral movement and breakage were noted from the tsunami

Isle Coco, St. Pierre

The coral reef at I. Coco was the farthest-east reef surveyed, and faced directly the path of the oncoming tsunami. St. Pierre is more sheltered, but both sites share a morphology of exposed granite rocks on their seaward side, and an extensive development of reef corals and carbonate framework in the shallows and in the lee of the islands. In both areas, corals on granite substrates showed little damage. However the reef frameworks of dead staghorn Acropora corals exhibited a near-total devastation. Sings 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 easy to move) 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. Damage to the reef framework was consistently estimated at > 50%. Corals close to the bottom on granitic surfaces showed evidence of breakage, likely due to rubble movement along the bottom.

La Reserve/Anse Petit Cours

This bay is west-facing, but was surveyed for two reasons: first, the shoreline and hotel suffered extensive damage, and second, this reef area suffered some of the lowest mortality of coral during 1998. Reef structure is slightly similar to Baie Ternai, with an extensive area of shallows leading out from the beach, and a sloping reef with high coral cover to a sand base at 6 m leading into deeper water. The island shoreline leading west from the bay is steeply sloping, with a fringe of coral growth at 1-10 m depth. Coral diversity was observed to be higher than other locations. 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. In particular, flattened areas of staghorn *Acropora* were common (e.g. *A. austera*), and damaged stands of the extensive columnar growth forms of *Goniopora*. Because of the sloping sand base, many Porites colonies in waters > 6 m were toppled, due most likely to erosion of sand from under one side and tumbling of the colony/boulder.

Mahe, north-east exposure

Anse Cimetiere, St. Anne

This site is an eroded unconsolidated reef that suffered high mortality in 1998. Among all sites on Mahe, damage to coral reefs was highest at Anse Cimetiere with at least 27% of colonies showing signs of physical and mechanical damage. The damage to this site is likely underestimated as most of the coral colonies that were damaged were completely destroyed and therefore were not included in the sampling methodology employed by SCMRT. Historical data of this site show that the reef slope has experienced an 80% reduction of coral cover as a result of the tsunami, from 20% to < 5%.

Baie Ternai

The coral reef of Baie Ternai Marine Park, on the northwest tip of Mahe Island, was among the most damaged sites on Mahe. It is a highly enclosed bay, with a reef crest dividing the inner seagrass/beach area from the outer deep bay, the reef crest being just below the surface and reef growth down to 8-10 m. Damage to corals was negligible below about 3 m, but > 10% of vulnerable branching corals at the reef crest were broken. A large proportion of the reef crest is dead branching corals from 1998, however the sheltered bay has enabled complete consolidation of branches and rubble by coralline algae, which prevented re-breaking of the framework by the tsunami. See 'seagrass' section, below, for a description of sedimentation impacts, and beaches around the east and west boundaries of Baie Ternaie were built up by sand deposition. Overall, compared to long term damage caused by coastal development, and coral bleaching during the El Niño of 1998, damage from the tsunami event was minor.

Anse Royale

The reef at Anse Royale is an old carbonate platform dominated by fleshy algae (*Sargassum*, *Turbinaria*) due to its highly exposed position to waves from the east and long term degradation from coastal land use. Tsunami damage was surveyed from a depth of 6 m, but 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

This is the southern-most point of Mahe island, and is a granite boulder field with abundant small corals. No evidence of damage was noted, to substrate or corals, between 0 and 10 m depth.

Anse la Mouche

Corals grow in a fringe of shallow patches and platforms within the bay at Anse La Mouche. Characteristic of sheltered backreef areas, they are dominated by opportunistic species on eroding substrates in the shallows, and deeper reefs dominated by large 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 and likely also be sediment displacement from underneath. In the shallows small branching corals were completely undamaged. Overall, coral damage was less than 5%. A layer of sediment appeared to have been removed from the reef, with extensive fields of fine rubble visible in the channels between coral heads.

Mahe, south-west exposure

Port Launay, West Rocks

This is a sheltered granitic site protected by granite rocks and is less susceptible to strong currents and wave action. It is also a relatively deep reef in comparison to the others assessed, lying in approximately 11 m of water. Damage here was consequently negligible.

Anse Copre

This site is composed primarily of seagrass, rubble and sand. The maximum depth on the reef observed was 3 m. No damage to corals was recorded.

Damage to seagrass beds

Sediment deposition, and associated eutrophication, or light and oxygen depletion can result in the mortality of seagrass beds. Seagrass habitats are essential feeding grounds for marine turtles and are critical nursery grounds for many fish species. Damage to seagrass beds in the Seychelles was low, with only one definite case of damage recorded at Baie Ternai Marine Park (above). Suspension of sediment and erosion of the reef channel resulted in the burial and smothering of the shallow seagrass area between the reef crest and beach inside the bay. Some of the seagrass areas appeared to be recovering as the excess sediment is being removed by normal tidal and wave action, exposing smothered seagrasses (though some still living) and dead pen shells. Mortality of pen shells (*Pinna* sp) living in the seagrass beds was high, with many of the shells now exposed 1-2 cm above the substrate. This may indicate a minimum depth of newly deposited sand, and (unsuccessful) attempts by the bivalves to burrow upwards to avoid smothering. At the boundary between seagrass beds and the channel, undercutting of the seagrass bed and exposure of roots occurred.

Marine Turtles

The impact of the tsunami on nesting sea turtles in the Seychelles seems to have been relatively minor and what impact there was appears to have been restricted to the inner islands. No obvious damage to nesting beaches was reported from any of the following sites in the outer islands (Jeanne Mortimer), Aldabra (Terence Mahoune), Farquhar atoll (Antonio "Mazarin" Constance), and D'Arros/St. Joseph (Jean-Claude Camille; pers. obs., J.A. Mortimer). Bird Island which monitors all their turtle nests reported "large tides" but no apparent damage to any of the nests (Margaret Norah). Aride Island monitors all their nests and reported two nests destroyed by the tsunami (Dylan Evans). Within the Marine Parks, no apparent damage was reported on the beaches of Ste. Anne Island (Jude Bijoux), but at Curieuse nests were lost in the vicinity of Anse Cimitiere but not in the vicinty of the most important nesting beach Grand Anse (Alain Cedras). At Curieuse, erosion at Grande Anse is the norm at this time of year, but the problem appears to have been exacerbated by the tsunami. At Intendence beach on Mahe no nest damage was recorded (Anders Dimblad).

Influence of reef flat geomorphology and shoreline damage

Lastly, an important correlation between coral reef location (coastal geomorphology) and shoreline damage was noted. Most damage to shorelines occurred where fringing reefs and bays with extensive coral development occur – e.g. Anse Petit Cours (Praslin), the causeway (Curieuse), Anse Royale (Mahe) and Anse la Mouche (Mahe). At these locations, development immediately above the high tide line was made possible by the protection offered by fringing reefs. However the reefs offered only limited protection from a wave the size of the tsunami, and protection was the least where depth was great – maximum damage occurred where reef channels cut in closest to land (the causeway at Curieuse, Anse Royale, Anse la Mouche). This was also observed in other countries, where tsunami impacts were greatly affected by bathymetry and shoreline morphology, and it is likely that these deep channels caused a focusing and build-up of energy from the waves, causing highest damage at the closest point of these channels to the shoreline. Maximising the protection benefits of coral reefs will involved maintaining healthy reef growth to minimize the depth of reef crests, and developing additional protection mechanisms along shorelines adjacent to channels.

Discussion

Major patterns of tsunami damage to reefs

Two major patterns in coral reef damage were noted, controlled by the geographic location of each island and exposure direction of each site, and reef substrate. 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 carbonate reef substrates. By contrast, sites around Mahe showed much lower levels of impact. The limited damage on Mahe is due to the shelter provided by the outer northern islands, and energy dissipation of the tsunami traveling over the greater distance of shallow water from the outer edge of the banks to Mahe.

Granitic reefs suffered less damage than reefs with a calcium carbonate substrate. Granitic surfaces were either immovable as they form the bedrock of the islands, or in the case of boulders and rocks, are too dense and of a compact 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. However the majority of true 'coral reef' sites in the granitic islands have a reef framework that is loosely consolidated due to mortality during the 1998 El Niño and subsequent bioerosion. This reef matrix was not robust enough to resist the tsunami waves, either from direct impact of the force of water, or movement of rubble and rocks. In these areas significant reef rubble was moved by the wave and consequently associated live coral colonies were also displaced and damaged.

Thus these preliminary assessments suggest that extensive damage was done by the tsunami to all coral reefs in northern and eastern island groups that have carbonate frameworks. It might be that this is also the case for outer atolls and islands, and surveys should be prioritized to the eastern islands closest to the tsunami origin. Little direct damage from the tsunami is expected for all coral reef habitats in the central, south and western parts of the granitic islands, and all outer islands sheltered by the Mascarene plateau and Seychelles bank (e.g. the Amirantes, Aldabra and others). In these areas, some damage is possible for shallow corals on carbonate substrates, but little damage is expected for all deeper habitats and all sites with granitic substrate.

Comparing these two patterns numerically, these surveys documented > 50% of substrate damage and >25% of direct damage to corals in northern and eastern-facing carbonate framework sites), <10% damage in shallow carbonate substrate sites in central, western and southern locations, and < 1% damage on all granitic substrate sites. Given the importance of coral reefs to the economy and social structure of the Seychelles (e.g. all the damaged northern sites are prime tourist locations for the country) this provides a strong threat to the country and requires action for mitigation.

Shoreline sensitivity and importance of reefs

The vulnerability of the low coastal plains to wave damage is clear from the tsunami. While fringing coral reefs protect these shorelines during regular conditions, their protection was limited during this extreme event. The GIS datasets used by the Seychelles government include a 'shoreline ranking' variable that characterizes the shoreline by substrate type (e.g. granite rock, coarse sand, fine sand, etc.). This provides a useful starting point for developing a shoreline vulnerability index to wave threats such as the tsunami and the consequences of climate change – sea level rise, northward migration of the cyclone belt and increases in storm frequency and intensity. A similar index should be developed that incorporates the wave-protection properties of the coral reefs (which enable beaches to accrete) versus granite shores, fine-tuned by vulnerability shown by shoreline damage to this tsunami event.

Since coral reefs are a primary shoreline protection asset for the people and developments on the coastal plains, their role in this, as well as for general tourism, biodiversity and fisheries, should be recognized, quantified, publicized, and incorporated into coastal and marine management regimes. Of particular importance to Seychelles' vulnerability to climate change will be the ability of reefs to continue growing upwards with rising sea level. In many cases (such as the fringing reef off Anse Royale, which is dominated by algae rather than coral) this will require protecting and enhancing the growth of reefs traditionally considered of low value for tourism and biodiversity.

Curieuse wall

An assessment of the damage to and repair needs of the causeway wall at Curieuse is urgently needed. This must be done before the change in monsoons results in wave damage to the previously sheltered mangroves. Mitigation activities will have to start by April 2005, if they are to meet their objectives.

Conclusions and Recommendations:

The impacts of the tsunami damage to coral reefs in the Seychelles were severe on the northern carbonate-framework reefs, but minor elsewhere. These damages, occurring while reefs were still recovery from 80-90% mortality of corals during 1998, point to a critical vulnerability of the coral reefs of the Seychelles. At this time, the primary reef carbonate frameworks in the granitic islands are relatively weak geological structures, consisting of attached and loose calcium carbonate pieces of varying sizes. These may become strongly consolidated by coralline algae growth over 5-10 years under good conditions (e.g. observation from Baie Ternai). The chemical and biological consolidation into a rigid reef framework, such as that found on some fringing reef sites (e.g. Anse Royale) may take hundreds to thousands of years. The El Niño in 1998 created extensive rubble fields from death and breakage of the fast growing branching corals (*Acropora* and *Pocillopora*) that dominate the shallow waters of Seychelles reefs. The impacts of the tsunami, 6 years later appear to have been exacerbated in these areas. Loosely consolidated reef frameworks were not able to resist the force of the waves, and loose rubble and rocks were carried by the waves.

In the short to medium term, mitigation activities will have to deal with the problem of loose reef frameworks and the long time needed for reef matrix consolidation, in order to promote coral reef recovery and growth. In the medium to long term, damage from the tsunami should be considered in the context of Seychelles as a Small Island Developing State. As such, it has a particular vulnerability to shocks and threats due to its small size, from natural disasters to economic and global political influences. While damage from the tsunami was not catastrophic on a wide scale to coral reefs, it was an additional major threat added to the catastrophic impact of coral bleaching 6 years previously. On the slowly recovering northen reefs, the tsunami set back biological recovery of corals by 6 years. Because of the extensive physical damage to the reef matrices, however, recovery of the overall reef may require much longer than that.

The interaction of these two types of threats in the medium to long term will be particularly important for the Seychelles – physical exposure to extreme waves events, and their increasing severity due to climate change – rising sea level, northwards migration of the cyclone belt in the southern Indian Ocean, and increasing severity and frequency of major storms. While the occurrence of another tsunami cannot be predicted, the increasing severity of the threat from waves to the Seychelles is clear.

Broader principles reflecting the importance of coral reefs to Seychelles should be developed (see box for examples) to guide the long-term protection of coral reefs and associated ecosystems. Specific recommendations center on three main areas with respect to coral reefs:

1. Mitigation of current damage – are there any options for enhancing recovery of damaged coral reefs from this tsunami event?

Principles for long term management of Seychelles coral reefs.

I. Improved capacity for assessment of coastal health and vulnerability to waves and storms, based on bathymetry, coastal topography and coral reef status;
II. Improved watershed management that minimizes downstream and marine impacts of water use and treatment, to maximize the recovery potential of coral reefs impacted in the past from eutrophication, overfishing and coral bleaching;
III. Integrated Coastal Zone and Marine Protected Area management plans integrated and designating use and protection status for all of Seychelles' coastal and EEZ waters, recognizing the coastal protection benefits of healthy coral reef ecosystems.

2. Development of a targeted coral reef and environmental monitoring programme to provide clear evidence for decision making with respect to coral reef recovery and protection, and enhancement of the contribution they make to the Seychelles economy.

3. Capacity building (technical training and provision of resources) to facilitate recommendation 2, particularly through improved resources for Marine Protected Area management and wider Coastal Zone Management.

Short term recommendations *(3-6 months)*

1. Mitigation of tsunami damage and enhancing coral reef recovery.

Rehabilitation and restoration technologies for coral reefs are in their infancy, and no current methods are feasible financially or logistically at spatial scales necessary for ecosystem-level processes. Nevertheless, pilot projects developed through local research institutions such as the SCMRT-MPA could be promoted. The key factors needed to be addressed are:

- substrate stability and the fixing or removal of mobile rubble from heavily impacted carbonate reef surfaces (e.g. Isle Coco, St. Pierre, etc.).
- water quality and ecosystem process improvements through coastal zone planning and freshwater management, and impacts from pollution and overfishing.
- Enhancement of natural recruitment and survival of small corals.

2. Replace lost Management Capacity of Curieuse Island Marine Park

3. Assess Curieuse Marine Park wall

Medium term recommendations (6 months to 2 years)

4. Development of coral reef and environmental monitoring capacity, SCMRT-MPA

As a part of the institutional structure of SCMRT-MPA, existing plans for environmental and resource monitoring need to be refined, implemented and expanded. In particular, we identify the following areas for capacity building in the medium term:

- An annual sampling plan, covering all priority sites within and adjacent to MPAs, be identified, with the frequency of sampling targeted at specific needs and activities, such as coral reef monitoring, use by divers, seasonal changes in fish populations, tsunami recovery processes, etc..
- Staffing needs for the monitoring plan be identified and built into individual-MPA and headquarters workplans, covering all aspects of prepration and planning, fieldwork, data entry and archiving and report writing.
- Based on current and projected staffing levels at SCMRT, the technical and managerial responsibilities for implementing the monitoring programme be split as part-time responsibilities. Technical responsibility, including liaising with external scientists and maintatin quality within the programme should rest with the Senior Researcher at SCMRT. Coordination and scheduling of the monitoring programme should be delegated to a more junior position, and include all aspects of fixing workplans and sampling times with MPA staff and monitoring partners.
- Additional monitoring equipment will be needed, such as underwater digital cameras, land cameras with zoom, Kayaks, VHF radios, etc.
- The involvement of a foreign senior researcher on a part time basis will help in developing and sustaining the monitoring programme – funds to facilitate for this should be raised, and a programme to build up the senior researcher at SCMRT at a counterpart.

In addition to the above systematic development of the monitoring programme, we identified the following areas in which changes can be made, to enhance rapid assessment, surveillance and reporting of monitoring activities:

- Access to many coral reefs and sea grasses around Mahe is difficult and expensive with current boat and diving protocols. SCMRT-MPA would benefit from using sea-kayaks to allow easy and quick access to nearshore environments.
- Large scale monitoring techniques are currently not being used in the Seychelles. The use of manta tow surveys (English et. al 1997) would enable the rangers to monitor reef and seagrasses rapidly and around many islands of the archipelago.
- Underwater digital cameras are essential for rapid data acquisition and communicating such physical impacts to marine habitats locally and internationally. This is especially important to the Seychelles as it is a relatively isolated archipelago.
- Land cameras equipped with strong zoom lens would also aid in documenting coastal damage and would also increase capacity for surveillance and enforcement in the Marine Park, a difficulty borne of the large areas to be monitored and the overstretched resources of the Marine Park Authority. Recommendations for 4 cameras with 35-400 mm zoom.

Enhanced monitoring capacity in other areas should also be developed:

- an accurate assessment of the impacts of the tsunami on Hawksbill Turtle nests is needed and tagging program should be continued to monitor population size and growth.
- Impacts to the local trap and other fisheries may occur and should be monitored.

5. *Strengthen the Seychelles Coral Reef Network*

Monitoring of coral reefs in the Seychelles involves a broad range of institutions and stakeholders, and has been built up over many years of short term projects and institutions. The Seychelles Coral Reef Network, currently chaired by SCMRT should be built up to ensure complementarity among monitoring programmes of participating institutions and projects. In particular, the follow groups, and current and recent programmes, should be consulted and their collaboration and information obtained to improve monitoring and management of coral reefs:

- SCMRT-MPA
- Conservation Department
- Seychelles Marine Ecosystem Management Project (SEYMEMP. Completed 2004)
- Living Oceans Foundation (Annelise Hagan)
- (Udo Engelhardt)
- Aldabra Marine Programme (Cambridge University)
- Cosmoledo/Aldabra group (Island Conservation Society/CORDIO)
- Global Vision International (volunteer-based monitoring, Cap Ternai (2004-2008?)

6. *Development of a shoreline vulnerability model and planning capacity*

Patterns of tsunami impact clearly demonstrated differential vulnerability of shorelines to waves impacts, and the role played by healthy coral reefs. Development of a shoreline vulnerability index (similar to the 'shoreline ranking' shown in detailed maps below), as part of a comprehensive national policy on coastline development and use will be necessary to minimize any future impacts from tsunamis, and from wave damage related to climate change. Additionally, detailed coastal bathymetry should be developed to enable predictions of wave-height and exposure to waves along the coastline. The policy should designate no build areas, define buffer zones around vulnerable beaches, coast lines, and reefs, and include management measures for maintaining and enhancing shoreline protection structures such as coral reefs..

Long term recommendations (3+ years)

Specific long term recommendations have not been identified focusing on coral reefs, as the medium term recommendations will lead to the defining of a longer term vision for coral reef management and protection as a national asset for the Seychelles.

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Table xx. Data table for rapid assessment surveys carried out during this assessment trip and by SCMRT (Coral Damage – SCMRT). All values relate to percent classes as follows: 0: zero; 1: 1-10%; 2: 11-29%; 3: 31-50%; 4: 51-75%; 5: 76-100% (see methods and ICRI/ISRS 2005). Calculated percent values for SCMRT damage measurements converted to percent class ranges.

Island	**Site**	**Substrate**	**Depth (m)**	**n**	**BENTHIC COVER**					**DAMAGE INDICATORS**					
					Live Coral			**Rock**	**Rubble**	**Coral**			**Substrate**		
					mean	**sd**	**max**			**SCMRT**	**CDAM**	**UPC**	**RBP/M**	**R<50**	**R>50**
OVERALL	OVERALL			160	1.0	1.0	4	1.6	2.4	1.1	0.3	0.3	1.3	0.4	0.2
Isle Coco	***OVERALL***				***1.0***	***0.6***	***2.0***	***2.1***	***1.9***	***#DIV/0!***	***0.4***	***0.1***	***2.2***	***1.1***	***0.6***
	Coco	coral	<3	23	0.5	0.7	2	1.0	2.7		0.7	0.2	4.2	2.0	1.0
	Coco	granite	2-12	13	1.5	0.5	2	3.2	1.1		0.0	0.1	0.2	0.2	0.2
Felicite	***NW Point***	***coral***	***6***	***6***	***0.0***	***0.0***	***0***	***1.5***	***3.3***		***0.0***	***0.0***	***4.5***	***2.0***	***0.0***
La Digue	***OVERALL***				***0.8***	***0.9***	***2.0***	***2.0***	***3.9***	***#DIV/0!***	***0.1***	***0.0***	***2.8***	***0.6***	***0.3***
	N Point	granite	2-6	5	1.0	1.0	2	2.4	3.6		0.2	0.0	3.0	0.0	0.0
	LaPasse	coral	2-6	6	0.7	0.9	2	1.5	4.2		0.0	0.0	2.5	1.2	0.5
Curieuse	***OVERALL***				***1.1***	***0.9***	***2.0***	***2.1***	***2.8***	***1.3***	***0.2***	***0.0***	***1.6***	***0.6***	***0.1***
	Coral Gardens	Coral	8	6	1.7	1.1	3	2.2	1.7	0	0.0	0.0	0.0	0.0	0.0
	Rafel Tournen	Coral								1					
	Caiman	Coral								2					
	Roskonon	Coral								2					
	Baie Launay	coral	2-6	10	1.1	1.1	2	2.1	2.9		0.2	0.0	1.6	0.3	0.0
	Grande Anse	coral	1-4	13	0.5	0.5	1	1.9	3.7		0.4	0.1	3.1	1.5	0.3
Praslin	***OVERALL***				***1.3***	***0.9***	***2.7***	***1.7***	***2.2***	***2.0***	***0.5***	***0.5***	***2.5***	***0.5***	***0.4***
	Anse Petite Cour	coral	<6	22	1.7	1.2	4	1.0	2.5	2	1.0	0.6	3.6	0.2	0.3
	StPierre	coral	<6	9	0.8	0.8	2	1.6	3.3		0.3	0.7	3.0	1.3	1.0
		granite	2-4	4	1.5	0.6	2	2.5	0.8		0.0	0.3	1.0	0.0	0.0
St. Anne	***OVERALL***				***#DIV/0!***	***#DIV/0!***	***#DIV/0!***	***#DIV/0!***	***#DIV/0!***	***1.5***	***#DIV/0!***	***#DIV/0!***	***#DIV/0!***	***#DIV/0!***	***#DIV/0!***
	Anse Cimetiere	Coral								2					
	Moyenne	Coral								1					
	Cerf														

Mahe-Exposed	***OVERALL***				***0.7***	***0.6***	***1.5***	***1.3***	***1.3***	***0.8***	***0.0***	***0.3***	***0.8***	***0.3***	***0.3***
East	Anse Royal	Coral	2	8	0.8	0.5	1	1.5	0.4	1	0.0	0.0	0.0	0.3	0.0
		Coral	6+							0					
North/west	Overall														
	Airport	Coral								1					
	Grand Rocher	Coral								1					
	Baie Ternaie	Coral		23	0.7	0.7	2	1.2	2.1	1	0.0	0.6	1.7	0.3	0.6
	Port Launay	Granite								1					
Mahe-Sheltered	***OVERALL***				***1.6***	***0.4***	***2.0***	***3.0***	***1.4***	***1.0***	***0.2***	***0.0***	***0.0***	***0.0***	***0.2***
South	Anse la Mouche	Coral	2	10	2.2	0.8	3	0.9	2.2	2	0.4	0.0	0.0	0.0	0.3
			6+							2					
	Point Police	Granite		2	1.0	0.0	1	5.0	0.5	0	0.0	0.0	0.0	0.0	0.0
	Anse Copre									0					

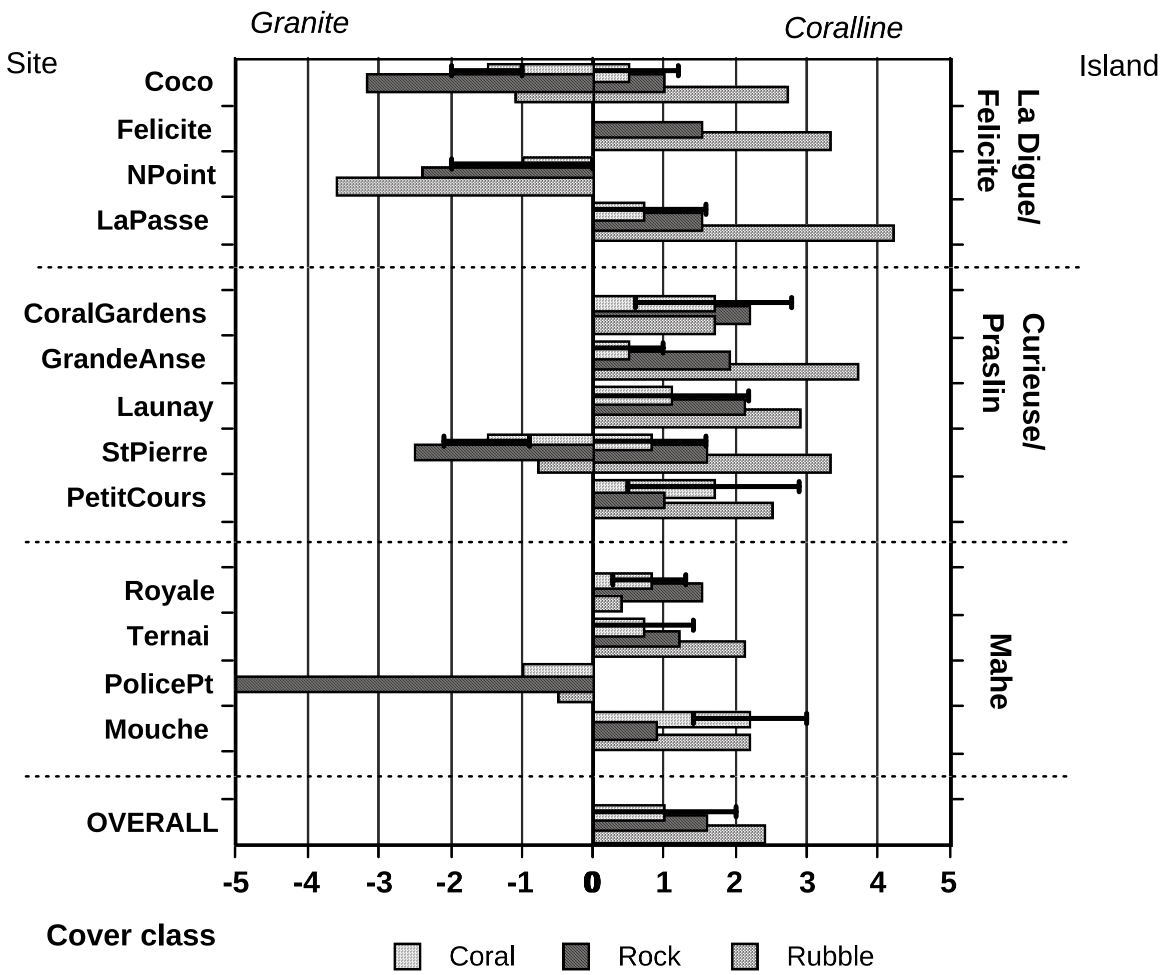

Figure xx. Benthic cover status at study sites on Mahe, Praslin and La Digue, separated by granitic or coralline substrate type.

Two year budget for the post-tsunami monitoring of coral reefs in the Seychelles inner islands

Actions	Items	No.	Cost in Seychelles Rupees (SR)	Cost in US$	Total Cost (US$)	Total in SR
Coordination of activities, data analysis and report preparation	Annual coordinator's salary, pension and social security	2	84000	15272	**30544**	**168000**
	Local transportation (yearly estimate)	2	5000	909	**1818**	**10000**
Monitoring	Data collectors salary (man days per year)	60	350	64	**3840**	**21000**
	Boat time (20 days yearly)	2	2000	364	**728**	**4000**
Equipment Procurement	Measuring tape	6	250	46	**276**	**1500**
	Quadrats	8	200	37	**296**	**1600**
	Coral tags	200	2	0.40	**80**	**400**
	Temperature loggers	8	650	118	**944**	**5200**
	Sediment traps	10	50	9	**90**	**500**
	Turbidity meter	3	1500	272	**816**	**4500**
	Digital Camera + casing	8	4400	800	**6400**	**35200**
Training	Flight of trainer from Europe or Australia	2	10000	1820	**3640**	**20000**
	Trainer's per diem (per day)	14	1200	218	**3052**	**16800**
	Training room	4	500	91	**364**	**2000**
	Boat time	4	2000	364	**1456**	**8000**
Public awareness and education	Production of brochures, leaflets, posters, field activities, TV spots	2	25000	4545	**9090**	**50000**
Miscellaneous	Yearly contribution towards repair and maintenance of boats	2	10000	1818	**3636**	**20000**
TOTAL					**67070**	**368700**