

GCRMN

GLOBAL CORAL REEF
MONITORING NETWORK

STATUS OF CORAL REEFS IN TSUNAMI AFFECTED COUNTRIES: 2005

EDITED BY CLIVE WILKINSON,
DAVID SOUTER AND
JEREMY GOLDBERG



Australian Government



**AUSTRALIAN INSTITUTE
OF MARINE SCIENCE**

Dedication

This book is dedicated to those people who were affected by the 26 December 2004 earthquakes and tsunamis. Their lives will have changed forever and they will all need the help and compassion that the world can provide to recover. This book is also dedicated to the International Coral Reef Initiative and partners, one of which is the Government of the United States, operating through the US Coral Reef Task Force. Of particular mention is the support to the GCRMN from the US Department of State and the US National Oceanographic and Atmospheric Administration.

Note: The conclusions and recommendations of this book have not been specifically endorsed by, or reflect the views of, the many organisations which have supported the production of this book, both financially and with content.

The research reported herein is based on early analyses of complex datasets and should not be considered definitive in all cases. Institutions or individuals interested in all consequences or applications of AIMS' research are invited to contact the CEO at the Townsville address given below.

Front Cover: Coral reef uplifted by the tsunami; Simeulue Island Sumatra; Craig Shuman, Reef Check Foundation, Los Angeles USA.

Back Cover: Maximum wave heights from the 26 December 2004 tsunami, from 10 to 2 m in dark red, 1 m in green/yellow to no waves in blue: Alessio Piatanesi, Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy. Maps were provided by ReefBase and the World Fish Center. We especially wish to thank Teoh Shwu Jiau.

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Office Locations:

Townsville, Queensland
PMB No 3, Townsville MC Qld 4810
Telephone (07) 4753 4444
Facsimile (07) 4772 5852

Darwin, Northern Territory
PO Box 40197 Casuarina NT 0811
Telephone (08) 8920 9240
Facsimile (08) 8920 9222

Perth, Western Australia
PO Box 83, Fremantle WA 6959
Telephone (08) 9433 4440
Facsimile (08) 9433 4443

www.aims.gov.au

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Notes: Only the key references specific for each chapter are included in the above; many of the unpublished reports and internet sites used to generate these chapters are not specifically referenced. The important baseline information can be obtained from organisations which have assisted in this publication or from Suggested Reading (Appendix I), particularly the chapters in the recent CORDIO (2005) and GCRMN (2004) on page 143. Data and information reported from internet sites in this book were obtained between October 2005 and February 2006.

We have used the singular 'tsunami' and more frequently the plural 'tsunamis' in this book. A single 'tsunami' (by definition a series of waves) was generated by the powerful earthquake event on 26 December 2004 that ruptured 1,300 kilometres of the fault line north to the Andaman Islands. This combined action generated many 'waves', which reflected off land masses and continental shelves to form a complex pattern of waves that lasted many hours. The use of 'tsunamis' is aimed to convey the concept that the damage was caused by many waves arriving from different directions, rather than a single massive wave.

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Many people assisted in gathering the information for this book, with the major contributions from the 60 authors and contributors of the national chapters and the geologists who translated the complex science of geomorphology and plate tectonics for the lay reader. Special thanks go to Phil Cummins, David Garnett, Viacheslav Gusiakov and Kenji Satake. These contributions simplified the task for the editors to combine material into the GCRMN 'Status Report' format. The reader is urged to seek the original texts and contact the contributors for more details. Not all reference sources are included; the principle sources of information are listed in the chapters and in Suggested Reading on p. 143. We apologise if some critical references and internet sites have been omitted. This report will be lodged by Karenne Tun and Marco Nordeloos on ReefBase, the global coral reef database at The WorldFish Center, www.reefbase.org and www.gcrmn.org. We wish to thank David Garnett, Joanna Ruxton, Madeleine Nowak, and Robin South for their careful editorial contributions. We owe staff at AIMS special thanks, especially the professional and friendly Science Communication team, Steve Clarke, Wendy Ellery and Tim Simmonds – thank you.

Parts of this report are being translated into the Thai language and we offer special thanks for Cherdtrak Virapat, assisted by Thamasak Yeemin, Maitee Duangsawasdi, Cherdchinda Chotiyaputta, and Yves Henocque for their assistance in producing that volume.

The GCRMN partners have assisted in the report: Gregor Hodgson brings the Reef Check network and volunteers; Jamie Oliver, Marco Noordeloos and Karenne Tun provide the ReefBase platform to ensure that GCRMN data can reach the world; and Olof Linden, David Obura, David Souter and Jerker Tamerlander coordinate the CORDIO program (Coral Reef Degradation in the Indian Ocean) that has generated and organised much of the information on the effects of the tsunami on the coral reefs of the Indian Ocean. The co-sponsors of the GCRMN have provided substantial assistance, advice and support: The Intergovernmental Oceanographic Commission of UNESCO; the United Nations Environment Programme (UNEP); IUCN - The World Conservation Union; the World Bank; the Convention on Biological Diversity; AIMS; WorldFish Center; and the ICRI Secretariat, held concurrently by Japan and Palau. These meet voluntarily in association with ICRI meetings to provide guidance to the GCRMN. Carl Gustaf Lundin Chairs the GCRMN Management Group and Bernard Salvat, Chairs the GCRMN Scientific and Technical Advisory Committee. He assisted with manuscripts and advise on the format and structure of the report. We wish to thank them all.

Support for the GCRMN comes primarily from the US Department of State, the National Oceanographic and Atmospheric Administration (NOAA) and the Australian Institute of Marine Science (AIMS); UNEP in Cambridge and Nairobi administers the funds. Without their support there would be no global coordination and no report – thank you. Funds to print this book have come from: the Government of the USA (Department of State and NOAA); the Australian Agency for International Development (AusAID); IUCN - The World Conservation Union; the United Nations Environment Programme (UNEP); WWF International; IOC - UNESCO; the Ministry of the Environment and the Nature Conservation Bureau of Japan; and the CRC Reef Research Centre for the Great Barrier Reef. Through their assistance, we can provide this book at no cost to people around the world who are working to conserve coral reefs, often voluntarily.

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AIMS – Australian Institute of Marine Science
WorldFish Center, and ReefBase
ICRI Secretariat – Governments of Japan and Palau
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GCRMN Operational Partners

Reef Check Foundation, Los Angeles
ReefBase, WorldFish Center, Penang
CORDIO – Coral Reef Degradation in the Indian Ocean, Sweden and Sri Lanka
World Resources Institute, Washington DC
NOAA – Socioeconomic Assessment group, Silver Springs.

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AusAID - Australian Agency for International Development
UNEP – Regional Seas, and GPA Coordination Office, The Hague, The Netherlands
IUCN – the World Conservation Union, Gland Switzerland
WWF – Europe
IOC-UNESCO - Intergovernmental Oceanographic Commission of UNESCO;
CRC Reef - Cooperative Research Centre for the Great Barrier Reef, Townsville Australia
Nature Conservation Bureau, Ministry of the Environment, Tokyo, Japan
IOI – International Ocean Institute

Hosts of the GCRMN

AIMS – Australian Institute of Marine Science
ReefBase at WorldFish Centre Penang
CRC Reef Research Centre Ltd
IMPAC- International Marine Project Activities Centre Ltd.

7. THE EFFECTS OF THE 2004 TSUNAMI ON MAINLAND INDIA AND THE ANDAMAN AND NICOBAR ISLANDS

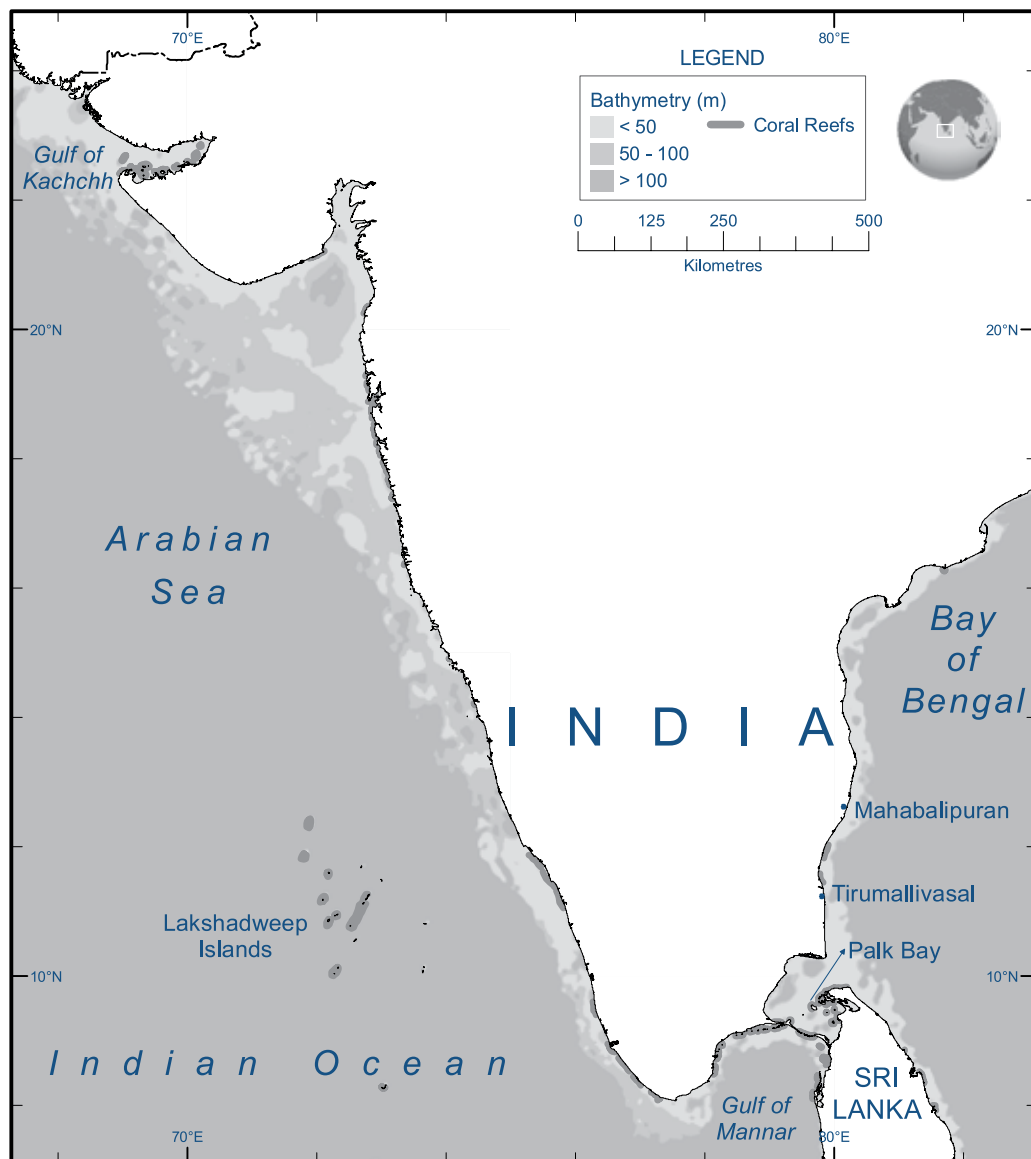
JK PATTERSON EDWARD, SARANG KULKANRI, R JEYABASKARAN,
SRI LAZARUS, ANITA MARY, K VENKATARAMAN, SWAYAM PRABHA DAS,
JERKER TAMELANDER, ARJAN RAJASURIYA, K JAYAKUMAR, AK KUMARAGURU,
N MARIMUTHU, ROBERT SLUKA, AND J JERALD WILSON

SUMMARY

- Mortality from the tsunamis was high, with more than 7,000 deaths in the Nicobar group alone (the final number may never be known as many indigenous people on remote islands may have perished). On the mainland, there were a similar number of fatalities ;
- The greatest losses were in fishing communities although the waves destroyed roads, jetties, other basic infrastructure and entire villages;
- There was major damage to the coastal resources of southeast India, particularly to mangrove and coastal forests. On the Andaman and Nicobar Islands there was considerable damage to the coral reefs and beaches, as well as the forests;
- The earthquakes changed the bathymetry of the coral reefs and coasts of the Andaman and Nicobars: reefs in the South Andamans to the Nicobars subsided by 1 - 3 metres; many reefs in the northern Andamans were uplifted out of the water and died; and some beaches have almost disappeared, while new beaches have formed;
- There was major damage to large areas of coral reefs of the Andamans and Nicobars, particularly due to debris being washed off the land and smothering by sediments;
- Mainland coral reefs in the Gulf of Mannar and elsewhere suffered very minor, localised damage. Many mainland beaches were seriously eroded; and
- The affected reefs are expected to recover within 5-10 years, if there is effective resource management and enforcement of legislation controlling destructive fishing, coral mining, over-harvesting of reef resources, coastal development, sedimentation and pollution.

INTRODUCTION

The first earthquake on 26 December 2004, initiated a chain reaction of earthquakes under the Andaman and Nicobar Islands that shook the entire Andaman Sea region. The end result was that the Burma Plate, which supports the Islands, tilted during an earthquake 'swarm' lasting



for about 8 minutes after the major quake off Sumatra. Thus, these islands were both a source of the tsunamis that spread out across the Indian Ocean and themselves impacted by tsunamis from the whole series of plate movements on that morning. The effects were very different on the mainland of India and the offshore Andaman and Nicobar Islands. For this reason, these 2 regions are discussed separately in this chapter.

Andaman and Nicobar Islands: Damage on the islands was caused by 2 events: the earthquakes and the subsequent tsunamis. Within 10 minutes of the earthquakes, waves as high as 15 m in the Nicobar group and 4 m in the Andaman group were washing over the islands. Buildings on Great Nicobar, Car Nicobar and Little Andaman islands were completely washed away, while



others, such as the Passenger Terminal at Phoenix Bay in Port Blair, collapsed as the ground shook. The waves killed more than 7,000 people in the Nicobar group alone and destroyed roads, jetties, and other basic infrastructure. The final number of fatalities may never be known as many communities of indigenous people on remote islands may have been lost. Relief efforts carrying supplies and aid to the Islands were delayed because of the distance from the mainland and because they are particularly rugged with few accessible ports or airports.

The subduction of the India Plate under the Burma Plate, which supports the Andaman and Nicobars, has changed the local coral reef and coastline topography. The whole Burma Plate tilted with shallow reefs from the South Andamans to the Nicobars being submerged by 1-2 metres, such that the previous reef flats are now several metres below sea level. However, in the northern Andamans, large sub-tidal areas were uplifted out of the ocean resulting in some of these reefs being permanently exposed; thus large areas of reef are now dead. Other changes to the coastal zones include some beaches disappearing due to major erosion, while other beaches have been created. Since 26 December, there have been more than 400 after-shocks, with some of the islands from the Southern Andamans to Nicobar Islands being raised by a further 20 - 25 cm. Nearly 6.8% of the land area of the Nancowry group is now submerged.

Mainland India: The tsunamis reached mainland India approximately 2 hours after the Great Sumatra-Andaman earthquake and reached the western Indian coast after about 3 hours. Although the east coast of Sri Lanka absorbed much of the wave energy, the waves still refracted around Sri Lanka and inundated coastal areas. The Tamil Nadu coast of southeast India was the worst affected region on the mainland, with serious damage to the coastal districts of Chennai, Cuddalore, and Nagapatinam Kanyakumari by waves between 2.5 and 5 m in height. Large areas along the Chennai coast were inundated up to 590 m inland. In some ports, the unusual tsunami currents dragged fishing boats out of the harbour.

The heavily polluted waters of the Adyar and Cooum Rivers were flushed out to sea as the tsunamis opened the river mouths, which are normally closed by sand banks. These river waters polluted the coastal environment with *E. coli* and *Salmonella* bacteria being found more than 10 km offshore. Furthermore, the increased nutrient loadings resulted in a phytoplankton and microbial bloom off the coast of Chennai.

STATUS OF CORAL REEFS PRE-TSUNAMI

Coral reefs in India cover approximately 5,790 km² and are divided into 3 major zones: the Andaman and Nicobar Islands; the coral reefs of the mainland; and the Lakshadweep Islands. Reef structure and species diversity vary considerably between these areas due to differences in size and prevailing environmental conditions. More than 260 hard coral species, 145 soft coral species, and 1,200 fish species have been recorded from Indian coral reefs.

Prior to the tsunamis, coral reefs along mainland India were heavily exploited and threatened by continual damage from destructive fishing, coral mining, over-harvesting of reef resources, coastal development, sedimentation and pollution. These threats were less severe in the

EWITNESS ACCOUNT FROM WWF-INDIA

The Andaman and Nicobar Islands were particularly hard hit by the tsunamis, claiming more than 10,000 lives. Most of the 356,000 residents on the remote island chain, including the majority who live in the capital city of Port Blair, were affected and thousands were made homeless. Some of the luckier ones were able to leave their homes for higher ground after high tide waters swept across low-lying areas. "It was the morning of December 26th when the first earthquake hit. About an hour later we heard people shouting all around saying that 'water is coming, water is coming'. Our house is surrounded by a creek and water suddenly rose and spilled over the bank and came rushing into the house. That is when my wife and I and our 2 dogs went to the back of the house, climbed a small hill and sat there for an hour before the water receded. We then went down to assess the damage; our house was seriously damaged from the earthquake and the sea water. The general mood was very grim. People have suffered. I lost everything I had acquired from all over the world during my 29 years of service in the Indian Navy and Coast Guard. This is a personal loss for me but life moves on. At the moment, our thoughts and actions are with the people who have suffered personal tragedies. It is certain, though, that people whose life and livelihood is the sea will return. After all, you can't expect fishermen to sit on a hill. Life has to go on" (from Debesh Banerjee, Honorary Secretary, WWF-India, Andaman and Nicobar Islands).

The number of hard coral species and genera decreases from the Andaman and Nicobar Islands to the isolated parts of the west coast of India.

Region	Number of Genera	Number of Species
Andaman & Nicobar Islands	43	134
Gulf of Mannar	36	128
Lakshadweep Islands	37	103
Gulf of Kachchh	24	37
West coast patches	17	29

Andaman and Nicobar Islands, where sedimentation and over-fishing were the most significant threats, affecting 55% of reefs. India developed a National Biodiversity Strategy Action Plan in 2004, which included a strategy for conserving coral reefs, although they were already protected under the Wildlife (Protection) Act of 1972. Despite the existence of several marine protected areas (MPAs), reefs in the region have continued to deteriorate due to increasing poverty among growing coastal populations, weak management practices and inconsistent monitoring activities.

The Andaman and Nicobar Islands are a remote chain of 530 islands, closer to Thailand than mainland India, and they divide the Bay of Bengal from the Andaman Sea. Although only 38 islands are inhabited, the population is growing rapidly, increasing from 279,000 in 1991, to 405,000 in 2001. Prior to the tsunamis, most of the islands were relatively pristine with extensive fringing reefs in good condition. The biodiversity of the Andaman and Nicobars is more similar to Southeast Asian reefs than South Asia, because the currents facilitate greater larval exchange with the reefs to the east. More than 1,000 fish species and 200 coral species have been identified. *Porites* species were dominant in the northern and southern Andaman Islands, while *Acropora* species were the most common on the middle Andaman and Nicobar

TSUNAMIS UNCOVER INDIAN SHRINES

Although the tsunamis caused considerable devastation, it also uncovered a few treasures: the remains of ancient, long-forgotten Indian seacoast shrines. The tsunami waves eroded the sands around 3 large rocks with elaborate carvings of animals, as well as the vestiges of 2 temples, near the coastal town of Mahabalipuram in Tamil Nadu. Mahabalipuram is well-known for ancient, intricately carved stone temples along the shore and these uncovered remains appear to be from a port city built in the 7th century. According to descriptions by early European writers, the area was home to 7 temples, 6 of which were supposedly submerged. The recently exposed 2 m rocks include an elaborately sculpted elephant head, a horse in flight, a reclining lion, and a small niche with a statue of a deity. According to archaeologists, lions, elephants, and peacocks decorated temples during the Pallava period in the 7th and 8th centuries. Archaeologists from the Archaeological Survey of India are continuing excavations. Director of excavations Alok Tripathi says there can be no doubt that the finds are from 8th century Hindu religious structures (from *Science*, Volume 308, Issue 5720).

TSUNAMI-HIT INDIAN FISHERMEN PREFER TO LIVE NEAR THE SEA

Even though the Government of Tamil Nadu, south India, has ordered people living along the tsunami-hit coast to build houses 200 metres away from the ocean, fishermen prefer to stay close to the sea. They say they have no option, since their livelihood is at risk. The new Government Order No 172 provides guidelines for building houses, and states that fully damaged houses within 200 m of the high tide line must now be built beyond the 200 m zone. If not, the Government will refuse assistance. Fishers have expressed serious displeasure at this order, "We do not fear the onset of another tsunami. We need to stay near the Ocean, because even the change in the colour of the sea or the nature of the wind along the coastline helps us identify what sort of fish we will catch that day. Our livelihood depends on the ocean" says Vanaja, a fisherwoman and a social worker. NGOs are now constructing houses along the coastline since the Government has refused assistance for buildings within the 200 m zone. "There are so many violations by tourist complexes and industrial set ups along the coast. Why isn't the Government taking them to task? Once we vacate maybe it will be handed over to private parties. It is very distressing that the district has not tackled this issue" says Jesuratnam, a social worker. The Government has already sanctioned 520 locations for land acquisition for permanent houses 500 m away from the coast (from www.newindpress.com and International Collective in Support of Fishworkers, icsf@icsf.net).

Islands. The 1998 bleaching event had little effect in the Andaman and Nicobars, and live coral cover averaged 65% before the tsunamis.

Mainland Indian coral reefs are found primarily in 2 locations: the Gulf of Mannar and the Gulf of Kachchh. There are also fringing reefs surrounding offshore islands along the central west coast. The marine environment in the Gulf of Mannar in southeast India has been declared as India's first marine biosphere reserve. Prior to the tsunamis, 530 fish species and more than 100 hard coral species had been identified. Coral reefs occur around 21 islands between Rameshwaram and Tuticorin, but 2 are now submerged due to coral mining. Live coral cover was estimated as 41% in 2004, with Keezhakkarai and Tuticorn Islands containing the highest cover, predominantly branching *Acropora* and *Montipora* species, as well as massive *Favia*, *Hydnophora*, *Goniastrea* and *Gonipora* species. The Thalayari Island and Upputhanni Island reefs were dominated by massive corals, while Kariyachalli Island and Anaipar Island were dominated by table corals (*Acropora cytherea* and *Acropora corymbosa*). The Tuticorn Island group had been severely degraded by coral mining so that coral diversity was poor. The reefs of the Vembar Island group consisted mostly of dead coral boulders and macroalgae assemblages.

There are shallow patch reefs growing on sandstone platforms around 34 islands in the Gulf of Kachchh. These reefs have low diversity because of the high salinity levels, large temperature fluctuations, and high sedimentation, with approximately 20% coral cover.

Lakshadweep Islands: The Lakshadweeps are made up of 12 atolls on the northern end of the Laccadive-Chagos ridge, where the 1998 bleaching event caused severe coral mortality. Live coral cover in the reef lagoons declined to about 10% in 2002, but it had increased to

DID ISLAND TRIBES USE ANCIENT LORE TO EVADE TSUNAMIS?

The Andaman and Nicobar Islands are Governed by India and are home to several hunter-gatherer tribes who have had very little contact with the outside world until fairly recently. Anthropologists initially feared the tribes could have been completely wiped out by the tsunamis. But Indian Air Force pilots flying sorties over the islands reported seeing men who fired arrows at their helicopters. Since then there have been reports that the islanders used their ancient knowledge of nature to escape the tsunamis. The first reliable reports on the fate of the Andamanese tribes indicate that most have survived. Their awareness of the ocean, earth, and the movement of animals has been accumulated over 60,000 years of inhabiting the islands. Oral history teachings and their hunter-gatherer lifestyle might have prepared them to move deeper into the forests after they felt the first trembles of the earthquake. The tribes present something of an enigma to anthropologists. The 4 Andaman tribes: the Great Andamanese; Onge; Jarawa; and Sentinelese, are known as the Negrito tribes of African descent. They are hunter-gatherers who lived mostly in isolation until 50 years ago, with little interaction with the outside world. They have been forced to withdraw deeper into the forests following recent encroachments and settlers penetrating their lands. Most tribes on the islands are endangered; threatened by disease, over-population, and lack of resources, and their numbers have dwindled to just a few hundred (from Bernice Notenboom, National Geographic News).

20% cover by 2004, with Kadmat and Agatti atolls showing good recovery. Kadmat Island was declared a marine protected area due to the importance of the reefs, seagrass beds and sea turtle nesting grounds.

STATUS OF CORAL REEFS POST-TSUNAMI

It was initially feared that there would be serious long-term damage to Indian coral reefs, including loss of habitat and nursery grounds. However, assessments throughout the region indicate that major long-term damage is unlikely.

Andaman and Nicobar Islands: The impact of the 2004 tsunamis on coral reefs in the Andaman and Nicobar Islands ranged from severe to minimal damage with about 40,000 ha of reef area destroyed. The most common damage resulted from debris, such as logs, being washed off of land and abrading and smothering corals. However, the most visible impacts resulted from the tectonic movements of the region which resulted in the permanent emergence of several reefs. The tsunamis were stronger on the west coast of North and Middle Andaman Islands, and on the entire South Andaman Island and Ritchie's Archipelago. Most coral mortality occurred in narrow channels where the tsunami energy was focused.

These islands are on the Burma Plate which was uplifted in the northwest and subsided in the southeast thereby increasing the average depths of reefs in the southern Andaman and the Nicobar Islands by 1-3 metres. Prior to the tsunamis, growth over large areas of coral reef flats (<2 m) had been restricted by sunlight and UV radiation exposure. Now these reefs are covered by several metres of water, which will promote more coral growth, and improved reef development in some areas, such as the Mahatma Gandhi Marine National Park.

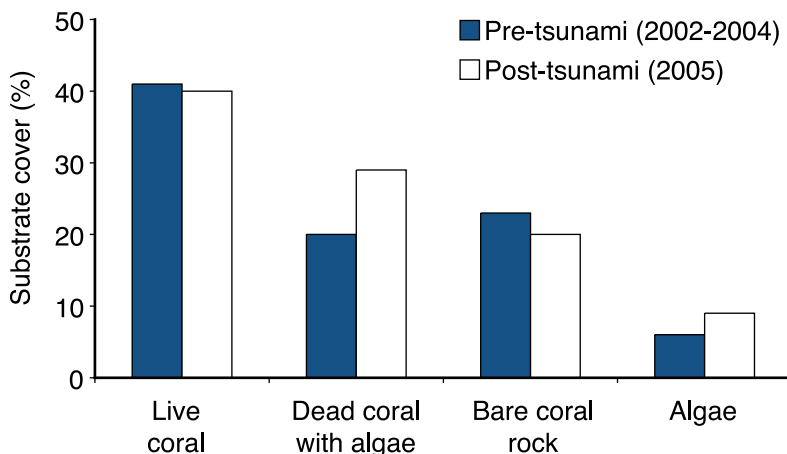
The South Andaman Island reefs have subsided by about 1 m and subsequent efforts to create barriers to the seawater to protect houses, paddy fields and other infrastructure have resulted in heavy siltation, which will damage the surrounding coral reefs. The mangroves in South Andaman have suffered extensive mortality where water depth has increased. However, mangroves in the northern group of raised islands where the water depth has decreased have survived, but could suffer increased mortality. In several areas, there has been significant damage to seagrass beds, but the effects on the endangered *Dugong* is not known.

Islands along the middle and northern Andaman Islands experienced the opposite phenomenon. The coral reefs were uplifted by 1-3 metres, totally exposing and killing corals on fringing reefs and reef flats. Corals growing on deeper parts of the reef are now exposed to increased wave action, heating and UV radiation; but will adapt to the more exposed conditions in the next few years.

Andaman Islands: Coral reef status was assessed in early 2005: first in the southern Andaman Islands and then in the Nicobars and northern Andaman Islands. These rapid assessments used scuba and snorkel to determine the nature and extent of the tsunami damage.

Jolly Buoys Island: The coral reefs were extensively damaged, with sediments smothering corals on the reef flats. Large amounts of debris were scattered over large parts of the reef. Some large coral colonies (>2 m diameter) were uprooted and scattered across the reef. Broken branches of *Acropora* spp. and *Hydnophora rigida* were frequently observed along the reef edge. Fish populations decreased in abundance and fish diversity declined.

Redskin: The coral reefs, including the dominant *Porites lutea* stands, were severely damaged. Although there was minimal damage on the reef flat, coral colonies on the reef slope were severely battered, with some large colonies breaking loose and being washed down to 15 m depth. Visibility has declined and the beach topography has changed. The beach has reduced in size and the slope has increased.



These data from 11 island sites in the Gulf of Mannar before and after the tsunamis show no significant change to coral cover from the tsunamis (from Patterson Edward).

Alexandra: Reef damage was similar to that in Jolly Buoys and Redskin, but less severe. Corals deeper than 15 m were covered by sediments. The *Acropora* species were most affected and a few colonies of *Porites lutea* were uprooted. Water visibility has been substantially reduced by the large sediment input.

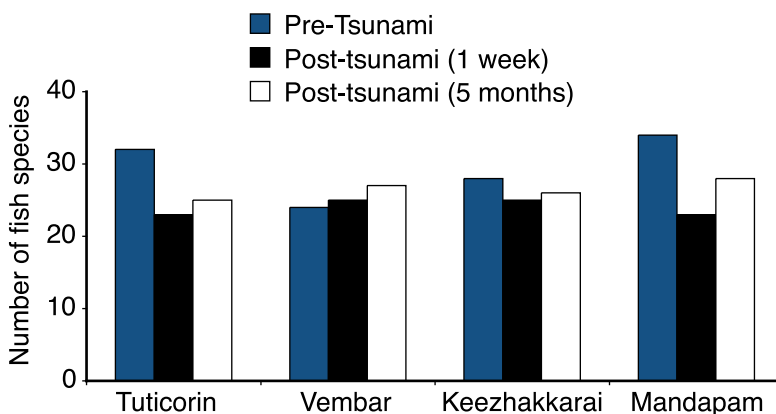
Grub: There was minimal impact from the tsunamis on these reefs with only a few colonies of *Acropora*, *Porites*, *Echinopora* and *Psammacora* species broken or toppled. Large *Acropora* colonies remained in excellent condition and now appear to be more abundant, whereas previously the reef was dominated by *Porites* and *Echinopora lamellosa*.

North Bay: This area is closer to Port Blair and showed very few tsunami-related impacts. The reef is dominated by *Porites lutea*, *Porites nigrescens*, and *Acropora* spp. and there were few sightings of broken colonies. However, the topography and composition of the beach has changed.

North Reef, Interview and South Reef: These were important turtle nesting sites, however, erosion from the tsunamis has washed the nests away and also raised the coral reefs, thereby creating major barriers for turtles to access the beach.

Nicobar Islands: There was greater damage from the tsunamis on the Nicobar Islands than on the Andaman Islands. Massive waves of 10-15 m killed thousands of people (mostly Nicobari tribes), virtually destroyed the coastal forests and levelled most of the island infrastructure.

There was major habitat alternation and new sections along many islands are now submerged, including Car Nicobar, Tarasa, Comorta, Trinkat, Nancowry, Katchal and Great Nicobar. The increased sediment stress has resulted in mass bleaching and mortality of corals; more than 70% of mainly *Acropora* species corals were uprooted and scattered over Sawai Bay in Car Nicobar Island. Trinkat Island has almost been split into 2 islands and sand was deposited over large areas of reefs on the west coast, killing the once dominant *Acropora* and *Porites* species. There was also major physical damage in the channel between Camorta and Nancowry, previously dominated by *Millepora*, *Acropora* and *Porites* species. Large colonies were uprooted,



There were no significant differences in fish diversity along 4 island groups of the Gulf of Mannar before and after the tsunamis (from Patterson Edward).

and pushed into shallow waters or washed into deeper water. The reef on the northeast of Nancowry, with extensive colonies of *Acropora* has almost disappeared. The largest leatherback turtle nesting site on Galathea Beach, Great Nicobar Island has vanished.

Mainland India: The Gulf of Mannar reefs were the only mainland reefs affected by the tsunamis. Some corals partially bleached while others were affected by increased siltation or from debris causing broken branches or toppled colonies. Although there was only slight damage to corals, coral reef habitat and associated fishery resources. Assessments at 11 randomly selected island sites (Vaan Island, Kariyachalli Island, Upputhanni Island, Pulivinichalli Island, Yaanaipar Island, Vali Munai Island, Thalayiari Island, Mulli Island, Poomarichan Island, Kurusadai Island and Shingle Island) estimated that the mechanical damage, impacts on benthic diversity and the deposition of debris, sand, silt and rubble were not significantly different from pre-tsunami surveys. However, some damage was visible: 1-2% of table and branching corals showed signs of physical damage, with many table corals (*Acropora cytherea*) overturned and many branching species with broken branches. Other impacts included seaweeds and seagrasses entangled in branching corals, sand deposition in approximately 25% of cup corals (*Turbinaria* spp.) and uprooted trees and soil erosion on 2 islands, Thalayiari Island in the Keezhakkarai group and Krusadai Island in the Mandapam group.

The Center for Marine and Coastal Studies of Madurai Kamaraj University observed similar trends in the Gulf of Mannar and Palk Bay. Massive corals, algae and seagrass beds were all unaffected by the waves although there was increased sedimentation in Palk Bay from 32.5 mg/day in November 2004 to 53.4 mg/day after the tsunamis. The Suganthi Devadason Marine Research Institute found that sedimentation rates have ranged from 50 to 110 mg/cm²/day on the Tuticorin coast since February 2003, and these were not affecting the corals. In January 2005, after the tsunamis, the sedimentation rate was 56 mg/cm²/day and also not damaging the corals. In May 2005, there was some coral bleaching in the Gulf of Mannar, especially on the Keelakarai and Tuticorin Islands where 34% of intertidal corals were bleached. Massive corals were most affected as sea surface temperatures reached 31.7°C and surface currents were abnormal. Live cover in the Tuticorin Islands declined from 42% pre-tsunami to 31% during post-tsunami surveys in January 2005. A large proportion of the corals were smothered by silt, leading to mortality.

There was no damage reported to the coral reefs of the Lakwadshoop Islands, Gulf of Kachchh and Grand Island offshore of Goa (where coral cover was 31% in 2002 and 36% in 2005).

The tsunamis had no significant impact on the abundance and distribution of reef fishes, with surveys around the Gulf of Mannar 1 week and 5 months after the tsunamis showing no change in species composition. The common coral reef fishes such as emperors (*Lethrinus*), rabbitfishes (*Siganus*), jacks (*Carangoides malabaricus*) and soldierfishes (*Sargocetron*) were all abundant. No impact was observed on crustaceans or molluscs.

Mangrove Damage: Satellite observations show that there has been major erosion of extensive mangrove areas along the eastern side of the Andaman and Nicobar Islands. North Andaman Island mangroves were largely unaffected, whereas those along the Middle Andaman Islands of Long, North Passage, and Porlob Islands were almost totally destroyed. South Andaman mangroves suffered minimal damage while those on Little Andaman Island suffered severe damage. Mangrove damage on the Nicobar Islands was island-specific; nearly all of the

GOVERNMENT LIFTS DEFORESTATION BAN FOR REBUILDING EFFORTS

As part of initial reconstruction efforts and the need to house the thousands that have been left homeless, the Andaman and Nicobar Islands have lifted a ban on felling trees. The logging permission will be in effect for 6 months, but does not include forests within 1,000 m of the sea, in national parks, sanctuaries, and coastal mangrove forests. While WWF recognizes the immediate need for timber for emergency housing, it is strongly advocating that timber for long-term reconstruction efforts should be harvested from responsibly managed forests. Indiscriminate logging could contribute towards other calamities in the future, such as landslides and flooding (from Mark Schulman, WWF International).

mangroves on Car Nicobar Island and Katchal Island were destroyed, and Comorta and Trinkat Islands lost about 80% of the mangrove forests. The mangrove forests of Tamil Nadu on the mainland were not seriously affected by the tsunamis.

Other ecological systems: Sand and sediments from land were deposited on the seagrass beds, with the potential to cause long-term stress to dependent dugong populations. Crustaceans, such as the giant robber crab, were also affected, and sea turtle nesting beaches at South Andaman, Little Andaman and the Nicobar Islands have almost vanished. These losses may reduce nesting by leatherback, green, hawksbill and Olive Ridley turtles, however new beaches forming nearby may provide adequate replacement nesting sites. The abundance of barnacles declined from 42% cover to 0% between 2002 and 2005 on the rocky reefs offshore of Muttom, Tamil Nadu and the barnacles have been replaced by fine turf algae, rubble and sponges.

Agriculture Damage: Sea-water intrusion was lower in areas of thick vegetation than on cleared lands. Sand deposition damaged standing crops in deltas and reduced land fertility, but, the potential effect on agricultural production is unknown.

Fisheries Damage: Fishing communities along the coastline probably suffered the most damage, with entire villages being destroyed, tremendous loss of life, and destruction of many houses, boats and fishing equipment. Many vessels broke free in ports and harbours, causing damage to other boats and infrastructure.

REHABILITATION AND RECOVERY EFFORTS

The Reef Watch Marine Conservation research station in Wandoor, South Andaman Island was substantially damaged by the tsunamis, but they were able to help relief efforts by distributing clothing, food and medicine to affected families. The Reef Research Team from the Institute for Environmental Research and Social Education (IERSE) is planning research on reefs and their resources for the benefit of coastal fishing communities that were affected by the tsunamis.

Since 2001, SDMRI has been conducting coral reef restoration efforts by coral transplantation. So far, over 100 m² have been restored.

The United States Agency for International Development (USAID) helped rehabilitate fishing and agriculture in India by providing assistance to redevelop local ports and other infrastructure. USAID

will also assist local governments with financial management plans and administration, and create links between municipal officials in damaged Indian cities with their counterparts elsewhere to share previous experiences and discuss best practices. More than 170 boats have been repaired and 232 boat engines and 200 fishing nets have been provided through a cash for work program; thus 300 fishermen from 4 villages surrounding Tirumallivasal have resumed fishing.

RECOMMENDATIONS AND CONCLUSIONS

The coral reefs of the Andaman and Nicobar Islands that were significantly damaged by the 2004 earthquake and tsunamis are likely to recover well within 5 to 10 years. The most probable long-term impacts will be on human activities such as fisheries, agriculture and forestry. The destruction of reefs and the loss of beaches may reduce local tourism in the archipelago; mainly diving and beach activities.

The tsunamis of 2004 caused little damage to the coral reefs of mainland India, however, these reefs remain under major threat from anthropogenic stresses. Unless destructive resource extraction and over-harvesting are better regulated, these reefs will continue to deteriorate. Thus, improved management and monitoring are needed. The more isolated Indian reefs on offshore islands continue to be threatened by global climate change. Recommendations for the sustainable management and long-term conservation of all affected coral reefs and their associated industries include:

- Establishing a regional network of marine protected areas to ensure ecological connectivity and proper enforcement;
- Increasing regulation of fishery resources, possibly through the introduction of certification schemes, improving legislation and patrolling to reduce poaching, and improving enforcement of existing regulations to ensure that fisheries are sustainable;
- Introducing government programs to raise community awareness of the status and importance of coral reefs and other coastal resources;
- Increasing funding to support coral reef monitoring and better management of coral reef data and information, including ecological and socio-economic data;
- Developing cooperative partnerships between all major stakeholders, government institutions and NGOs;
- Increasing the focus on the development of alternative livelihoods to reduce the pressure on reef resources;
- Undertaking research on the current conservation status of coral reefs and associated fauna;
- Increasing legislation and enforcement activities related to poaching and exploitation of marine resources; and
- Increasing funding to key institutions and ensuring that they operate transparently and effectively.

REVIEWER

Kristian Teleki.

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AUTHOR CONTACTS

Jerker Tamelander, IUCN Asia Regional Marine Programme CORDIO and GCRMN, jet@iucnsl.org; JK Patterson Edward, Suganthi Devadason Marine Research Institute, jkpatti@sancharnet.in; K Jayakumar, AK Kumaraguru, N Marimuthu, and J Jerald Wilson, Madurai Kamaraj University, kjkkumar@yahoo.com, akkguru@eth.net, marinemari@hotmail.com and jjeraldwilson@hotmail.com; R Jeyabaskaran, National Coral Reef Research Institute, jeybas@hotmail.com; Sarang Kulkanri, Reef Watch Marine Conservation, sarang@reefwatchindia.org; Sri Lazarus, Institute for Environmental Research and Social Education, lazarus_lasu@yahoo.com; Anita Mary, WWF-India, marineani@rediffmail.com; Arjan Rajasuriya, National Aquatic Resources Research & Development Agency, arjan@nara.ac.lk; Robert D Sluka, Millennium Relief and Development Services, bobsluka@mrds.org; K Venkataraman, National Biodiversity Authority, nba_india@vsnl.net.

REFERENCES

- Kumaraguru AK, Jayakumar K, Wilson JJ, Ramakritinan CM (2005) Impact of the tsunami of 26th December 2004 on the Coral reef environment of Gulf of Mannar and Palk Bay regions in the southeast coast of India. *Current Science*, 89(10): 1729-1741.
- Marimuthu N, Wilson JJ, Kumaraguru AK (2005) Teira batfish, *Platax teira* (Forsskal, 1775) in Pudhumadam coastal waters, drifted due to the tsunami of 26 December 2004. *Current Science*, 89(8): 1310-1312.
- Wilson, JJ, Marimuthu N, Kumaraguru AK (2005) Sedimentation of silt in the coral reef environment of Palk Bay. *J.Mar.Biol.Ass.India*, 47(1): 83-87.
- Patterson Edward JK(2005) Pre and post tsunami reef status in Gulf of Mannar. Suganthi Devadason Marine Research Institute – Reef Research Team (SDMRI-RRT).
- Kulkarni S (2005) Tsunami impact assessment of coral reefs in Andaman and Nicobar Islands: Interim report. Reef Watch Marine Conservation, Mumbai, India, funded by CORDIO.
- Space Applications Centre (ISRO) (2005) Assessment of damages to coastal ecosystems due to the recent tsunami: summary report. Ministry of Environmental and Forests, Government of India, 36 pp.

