MANGROVES:
Nature's defence against
TSUNAMIS

A report on the impact of mangrove loss and shrimp farm development on coastal defences

A report by the

Environmental Justice Foundation

CONTENTS

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COVER PHOTOGRAPHS: *Banda Aceh, Indonesia, before and immediately after the tsunami struck. Shrimp and fish ponds which had been built on mangrove forest areas, together with the town behind, suffered almost total destruction.*

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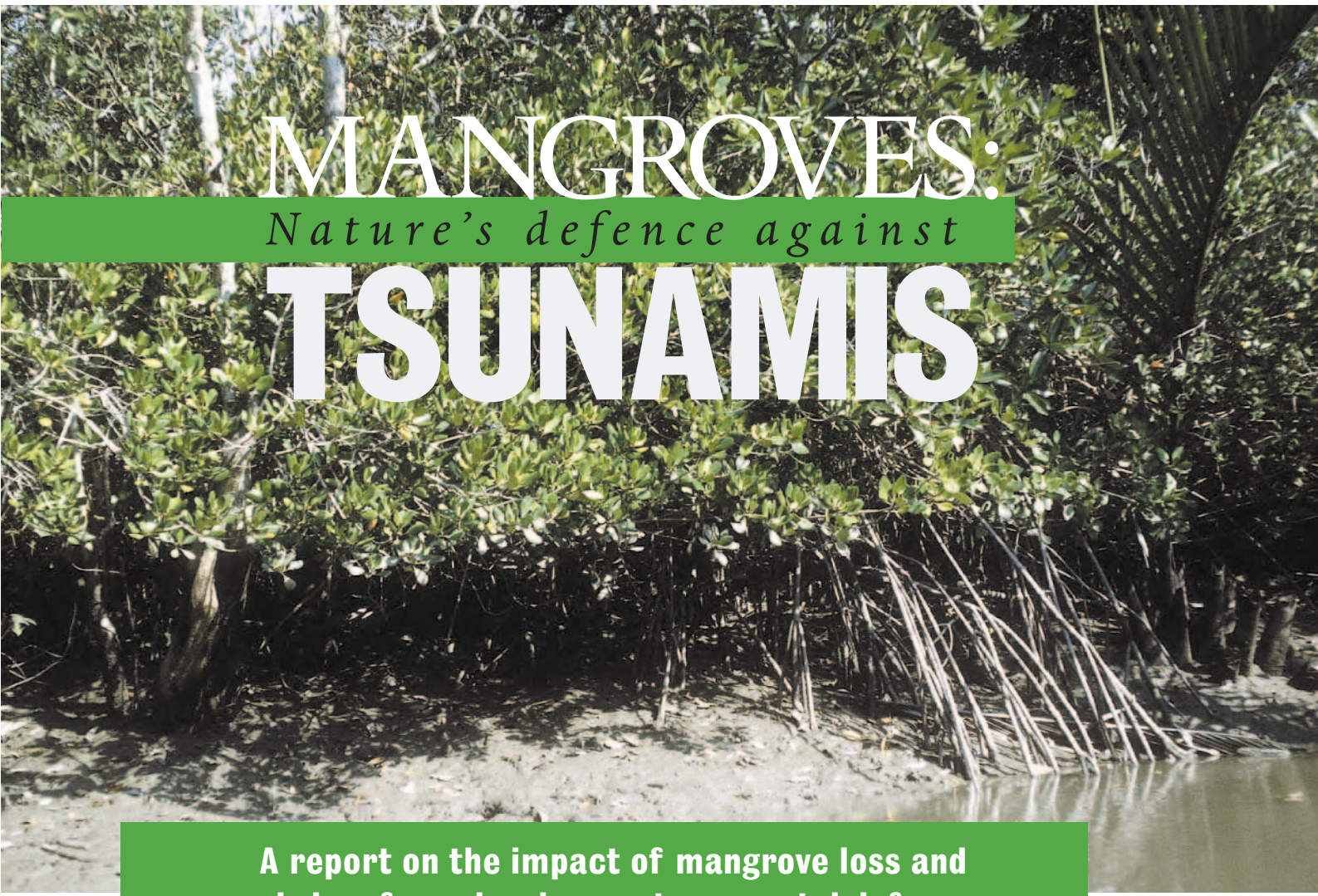

MANGROVES:
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A report on the impact of mangrove loss and shrimp farm development on coastal defences

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EXECUTIVE SUMMARY

- In the aftermath of the 2004 tsunami, compelling evidence has emerged from field studies in several affected countries, indicating that mangrove forests played a crucial role in saving human lives and property. Greenbelts of other trees, vegetated coastal dunes, seagrass beds, and intact coral reefs all performed a similar protective function in some areas. Where mangroves and other coastal habitats had been destroyed, often illegally, the waves were able to penetrate far inland, destroying homes, inundating farmland and washing away people and livelihoods.

- This report concludes that the conversion of mangrove habitat into shrimp farms, tourist resorts, agricultural and urban land over the past decades, as well as destruction of coral reefs, contributed significantly to the catastrophic loss of human lives and settlements during the 2004 tsunami. Conserving and restoring coastal mangrove areas is essential if coastal communities are to recover and be protected from future similar events. Although the occurrence of another natural disaster of the scale of the Boxing Day tsunami is very unlikely in the near future, other threats such as cyclones, hurricanes and increased sea levels will potentially ravage coastlines across the Indian Ocean on a far more regular basis.

- Forty percent of global mangrove cover is in Asia, but the region has also experienced the highest loss of mangroves over the past decade, which has been primarily attributed to the development of aquaculture and tourism infrastructure.

- All of the countries that were hit hardest by the tsunami – Indonesia, Sri Lanka, India and Thailand – have experienced recent net losses of mangrove cover. Between 1980 and 2000, the total area of mangroves in these four countries was reduced by 28%, from over 5 million to 3.6 million hectares. Indonesia possesses the largest mangrove area of any country, with over 3 million hectares of mangroves (30% of the global total), but also accounts for the loss of over 1.1 million ha of mangrove forest since 1980.

- The marine fisheries and aquaculture sector bore the brunt of the tsunami, with the material losses of fisherfolk across the Indian Ocean estimated at US$520 million. In Aceh, Indonesia, 20,000 hectares of aquaculture ponds were damaged or destroyed (there were 47,000 hectares prior to the tsunami), whilst in India and Thailand farmed shrimp production during the first six months of 2005 dropped dropped by 5% and 27%, respectively, compared with the equivalent period in 2004.

- Globally, mangrove forests are among the most threatened habitats, with rates of loss exceeding those of rainforests and coral reefs. The development of shrimp aquaculture poses the gravest threat to the world's remaining mangroves, and one estimate has attributed 38% of recent mangrove loss to the industry. Other detrimental human activities include over-harvesting of wood for fuel and timber production; land clearance for agriculture and coastal development; mining; pollution; and damming of rivers, which alters water salinity.

- Worldwide, shrimp farming has grown at an annual average of over 18% since 1970, and is the single most valuable internationally traded seafood product worldwide, valued at an estimated $50-60 billion at the point of retail. Shrimp aquaculture production is driven by increasing demand from consumers in Europe, North America and Japan, but is almost totally restricted to developing countries, and is especially concentrated in Asia (more than 80%).

- Thailand, Indonesia and India are among the world's top producers and exporters of farmed shrimp, but the substantial wealth generated by the industry has been offset by numerous and significant negative environmental impacts. In Thailand, mangrove cover virtually halved between 1975 and 1993, from 312,000 ha to 168,000 ha. Shrimp farming is estimated to be responsible for 50-65% of this loss since 1975. In Indonesia, 269,000 ha of the country's mangroves were converted into shrimp ponds between 1960 and 1990.

- Reconstruction efforts have been ongoing over the past year in a bid to provide employment and revive local economies. It is imperative, however, that shrimp farms are not restored to their previously unsustainable state. EJF contend that an opportunity exists for governments and industry to redress past mistakes and invest in aquaculture practices that are environmentally, socially and economically viable, sustainable in the long-term, and truly beneficial for the impoverished and vulnerable coastal communities that have suffered most from the tsunamis impact.
- The role of mangroves in preventing coastal erosion and protecting against typhoons, cyclones and hurricanes, is well documented. The trees both shield the land from wind and trap sediment in their roots, maintaining a shallow slope on the seabed that absorbs the energy of tidal surges. In addition, analytical models have shown that mangroves can buffer coastlines during tsunami events. Mangrove forests reduce the impact of tsunamis by reducing both the height and the velocity of the incoming waves, and by distributing water among the canals and creeks of the mangroves, thus decreasing the level of inundation.
- Mangroves represent far more than just a 'bio-shield'. Despite being regarded for many years as 'wastelands', ripe for development, it is now known that mangroves provide coastal communities with many services and utilizable products, and perform vital ecosystem functions. According to the Millennium Ecosystem Assessment of the United Nations Environment Programme: "Intact tropical mangroves, coastal ecosystems that are nurseries for fish, natural pollution filters and coastal defenses, are worth around $1,000 a hectare. Cleared for shrimp farms, the value falls to around $200 a hectare."
- The governments of tsunami-affected countries are now admitting their folly in squandering mangrove forests and have announced massive rehabilitation programmes in an attempt to rectify, at great expense, the losses of the past decades. It is symptomatic of the way in which mangroves have been consistently under-valued, that it has taken a catastrophic event of this magnitude for their importance to become widely recognized.
- EJF call on governments to ensure restoration and provide far greater protection for mangroves and other coastal habitats damaged both by the tsunami and, far more significantly, by chronic human misuse.

ABOVE LEFT: *The destruction of mangroves and other coastal habitats to make way for shrimp farms, tourism, agriculture and urban development left coastal populations vulnerable and exposed when the tsunami struck.*

INTRODUCTION

Shortly before 8am local time on 26 December 2004, a colossal shift of tectonic plates triggered a magnitude 9.15 earthquake in the Indian Ocean, 150km off the west coast of north Sumatra, Indonesia.

The energy released caused the seabed to rise by several metres, displacing an estimated 30 km^3 of water and triggering a series of devastating tsunami waves. More than 230,000 people perished, and millions were left destitute, as ten metre high waves struck the coastlines across 13 countries. Four of these – Indonesia, Thailand, Sri Lanka and India – account for the vast majority of those killed.

The tsunami razed entire towns to the ground, sweeping away buildings, bridges, cars, and, for those that survived its impact, left behind shattered livelihoods. The fisheries sector was particularly badly hit: many thousands of fishing boats and gear were lost, and ports and other landing sites destroyed. For coastal communities reliant on farming, the tsunami ruined crops, drowned livestock and poisoned arable land and water supplies with salt.

Mangroves and other coastal habitats, where still in existence, met the tsunami head on. In doing so, they shielded lives and property, but were also heavily impacted. Mangroves and other littoral forests were in places broken and uprooted, and coral reefs spectacularly overturned, but in many cases initial fears of serious ecological damage were proved untrue.

One pattern that has consistently emerged, however, from post-tsunami environmental assessments, is that healthy ecosystems fared much better, and had a much greater protective function than those denuded by human activities. It is also important to recognise that despite the thousands of hectares of mangroves, coastal forest, and coral reefs destroyed by the tsunami, human activities prior to the tsunami had inflicted far greater and more serious damage than could be wrought by any natural event, even one of the enormity of 26th December 2004.

This report summarises current knowledge and understanding of the protective role of mangroves and other coastal ecosystems against tsunamis and extreme weather events. It concludes that mangrove forests and coral reefs play a potentially life-saving role in offering coastal defences and that the unplanned and unsustainable destruction of these vital natural assets has left coastal communities increasingly vulnerable. In the Tsunami event this resulted in the additional loss of life and livelihoods.

RIGHT: *The countries most directly affected by the 2004 Indian Ocean earthquake.*

A small price to pay for environmental justice

£5 / $6 per month could help kids get out of the cotton fields, end pirate fishing, protect farmers from deadly pesticide exposure, guarantee a place for climate refugees

This report has been researched, written and published by the Environmental Justice Foundation (EJF), a UK Registered charity working internationally to protect the natural environment and human rights.

Our campaigns include action to resolve abuses and create ethical practice and environmental sustainability in cotton production, shrimp farming & aquaculture. We work to stop the devastating impacts of pirate fishing operators, prevent the use of unnecessary and dangerous pesticides and to secure vital international support for climate refugees.

EJF have provided training to grassroots groups in Cambodia, Vietnam, Guatemala, Indonesia and Brazil to help them stop the exploitation of their natural environment. Through our work EJF has learnt that even a small amount of training can make a massive difference to the capacity and attitudes of local campaigners and thus the effectiveness of their campaigns for change.

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Protecting People and Planet

THE IMPORTANCE OF MANGROVE WETLANDS

The term mangrove refers to a diverse group of salt-tolerant trees and other plant species that are found along sheltered tropical and subtropical shores and estuaries[2,3]. Mangrove wetlands are home to many rare animals and plants, but also have wider ecological and economic importance, and provide numerous services to humans[2,3,4].

Mangroves prevent coastal erosion, and act as a barrier against typhoons, cyclones, hurricanes, and tsunamis, helping to minimize damage done to property and life[2,4,5,6]. Mangrove tree species that inhabit lower tidal zones can block or buffer wave action with their stems, which can measure 30m high and several metres in circumference[4]. The trees both shield the land from wind and trap sediment in their roots, maintaining a shallow slope on the seabed that absorbs the energy of tidal surges[7].

The loss of mangroves can prove disastrous, as evidenced by past events. In the Indian state of Orissa, where the low-lying coastline has been stripped of mangroves to make way for shrimp farms, a cyclone in 1999 left approximately 10,000 people dead and around 7.5 million homeless[7]. Although the cyclone affected over 250km of Orissa's coastline, it was only a highly denuded area of 100km through which water surged[8]. Other areas with intact mangrove forests were largely unaffected[8,9]. Scientists concluded that the replacement of mangroves with shrimp farms had greatly exacerbated the impact of the cyclone and had cost many lives as a result[7]. Several other cases where mangroves have been shown to reduce the effects of cyclones, typhoons and tidal waves are known[10].

A series of experiments carried out by the EqTAP project (Development of Earthquake and Tsunami Disaster Mitigation Technologies and Their Integration for the Asia-Pacific Region), funded by the Japanese government, have shown that mangrove forests and certain other types of coastal vegetation can effectively reduce the impact of tsunamis on coastlines[11,12,13]. Empirical and field based evidence is limited, but analytical models show that 30 trees per 100m² in a 100m wide belt may

'Mangroves contribute directly to rural livelihoods by providing wood and non-wood forest products – including timber, poles, fuelwood and thatch for houses – and indirectly by providing spawning grounds and nutrients for fish and shellfish. Mangroves can also help protect coastal areas from tidal waves.'

METTE LØYCHE WILKIE, FAO EXPERT ON MANGROVES[1]

reduce tsunami flow rate by as much as 90%[14]. EqTAP recommend using a coastal green belt to protect homes, as it is sustainable, and much cheaper than artificial barriers[11,12,13]. Studies in Vietnam also demonstrate the usefulness of mangrove forests in coastal protection[6].

Mangrove forests store and process huge amounts of organic matter, dissolved nutrients, pesticides and other pollutants that are dumped into them by human activities[2], and by absorbing excess nitrates and phosphates prevent the contamination of coastal waters. In so doing, they play a vital role in protecting coral reefs and seagrasses from siltation and eutrophication[2]. Mangroves also function as a sink for atmospheric carbon dioxide, a major contributor to global warming[4].

Although they are not particularly species rich, mangrove ecosystems are important nursery areas and habitats for commercially valuable shrimp, shellfish, and fish species[2,4,15]. Globally, nearly two thirds of all fish harvested depend on the health of wetlands, such as mangroves, seagrasses and coral reefs for various stages in their life cycle[16]. An authoritative study carried out by an international group of scientists in the Caribbean, found that mangroves play a vital role in nurturing and protecting juvenile coral reef fish[17]. Coral reefs were found to have more than twice as many snappers (*Lutjanus apodus*) and grunts (*Haemulon sciurus*) where healthy mangrove forests were found nearby. However, the destruction of mangroves may have caused local extinction of one of the largest herbivorous fish in the Atlantic – the rainbow parrotfish (*Scarus guacamaia*). The researchers concluded that if the current rate of mangrove deforestation continues there are likely to be serious impacts on ecosystems and the productivity of fisheries[17].

People derive many harvestable benefits from mangrove forests: wood for fuel, furniture and construction, a source for charcoal, tannin, paper, dyes and chemicals, thatch, honey and incense. The foliage of mangrove species is used to feed livestock, and several mangrove plants are used for traditional medicine[18,19,20].

ABOVE: *Honey gathering in the Sundarban mangrove forest.*
© Shehzad Noorani / Still Pictures

OPPOSITE TOP: *Mangroves, Thailand.*
© Bojan Brecelj / Still Pictures

OPPOSITE BOTTOM: *Fishing in the Sundarban mangrove forest.*
© EJF

MANGROVES —A HABITAT UNDER THREAT

ABOVE: *Degraded mangroves, Vietnam.*
© EJF

'In many countries and regions, mangrove deforestation is contributing to fisheries decline, degradation of clean water supplies, salinization of coastal soils, erosion, and land subsidence, as well as release of carbon dioxide into the atmosphere.'

PROFESSOR EDWARD BARBIER & DR MARK COX, 2003[22]

FIGURE 1: *Area of mangrove habitat destroyed worldwide by different human activities. Shrimp aquaculture is, by a considerable margin, the greatest single cause of mangrove loss.*[25]

- Shrimp aquaculture 38%
- Forest use 26%
- Fish aquaculture 14%
- Diversion of freshwater 11%
- Land reclamation 5%
- Herbicides 3%
- Other 3%

'The rapidly expanding shrimp aquaculture industry poses the gravest threat (to mangroves)'

UNITED NATIONS ENVIRONMENT PROGRAMME[21]

The Indian Ocean has some of largest and most important mangrove forests in the world, and the Indo-Malaysian region is considered to be the cradle of mangrove evolution[2]. Forty percent of global mangrove cover is in Asia[23,24], with the remainder growing along the tropical coasts of Africa and the Americas. However, Asia has also experienced the highest loss of mangroves over the past decade[25], which has been primarily attributed to the development of aquaculture and tourism infrastructure[25].

Other human activities that are contributing to the loss and degradation of mangrove habitat include over-harvesting for fuelwood and timber production; land clearing for agriculture and coastal development; mining; pollution; and damming of rivers, which alters water and soil salinity[2,3,26].

Mangrove forests are among the most threatened habitats in the world today, with rates of loss exceeding those of rainforests and coral reefs[27]. Three-quarters of the coastlines of the tropical and subtropical countries were once covered with mangroves, but less than half of this remains, and half of the remaining forests are degraded[2]. Globally, the rate of decline in mangrove forest cover has been estimated at more than 2% per year[27].

According to the Mangrove Action Project, an international network of over 400 NGOs and over 250 scientists and academics from 60 nations, the shrimp aquaculture industry is the greatest threat to the world's remaining mangroves[28]. A 2001 study estimated that 38% of recent mangrove loss may be attributable to shrimp farm development[27]. In Thailand, shrimp farming alone has caused the loss of 65,000 ha of mangroves[2].

Most of the damage to mangroves from shrimp farming is caused by direct conversion of mangrove land to shrimp ponds. Inorganic or organic pollution produced by shrimp farms can also lead to or exacerbate mangrove degradation[10].

Worldwide, shrimp farming has grown at an annual average of over 18% since 1970, and is the single most valuable internationally traded seafood product worldwide[29], valued at an estimated $50-60 billion at the point of retail[30]. Shrimp aquaculture production is driven by increasing demand from consumers in Europe, North America and Japan, but is almost totally restricted to developing countries, and is especially concentrated in Asia (more than 80%)[29].

All of the countries that were hit hardest by the tsunami – Indonesia, Sri Lanka, India and Thailand – have experienced recent net losses of mangrove cover. According to FAO statistics, between 1980 and 2000 the total area of mangroves in these four countries was reduced by 28%, from 5,054,900 to 3,660,600 hectares[31].

EVIDENCE OF TSUNAMI PROTECTION FROM MANGROVES

'The role of mangroves in providing coastal protection against the actions of waves, wind and water currents is well known.'

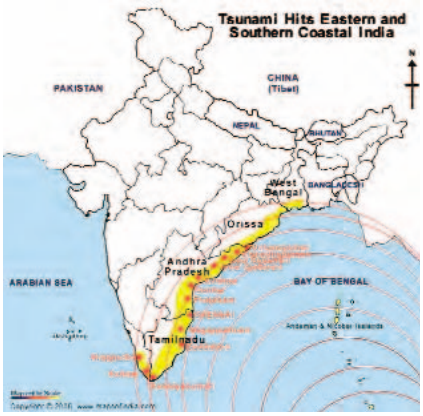
Mette Løyche Wilkie, FAO expert on mangroves[1]

© Reefbase

'Those coastlines with intact coral reefs, mangroves, vegetated dunes and robust coastal forests came off better than those degraded by pollution and insensitive land use.'

Klaus Toepfer, Executive Director, United Nations Environment Programme[32]

In the aftermath of the tsunami, as the full scale of the tragedy unfolded, many reports emerged from scientists, environmentalists and local people, of cases where mangrove forests had saved lives and property. Mangroves not only broke the impact of the waves, but also trapped debris and prevented people from being washed out to sea, which was a major cause of death[33]. However, where coastal habitats had been encroached upon, often illegally, to make way for shrimp farms, agriculture and urban development, the waves were able to penetrate far inland, destroying homes, inundating farmland, and washing away people and livelihoods.



India

Hundreds of coastal communities in the southern Indian states of Kerala, Tamil Nadu and Andhra Pradesh, and the Union Territories of Pondicherry and the Andaman and Nicobar Islands, were devastated by the tsunami, which claimed over 10,000 lives[34]. Loss of life and property was most severe in Tamil Nadu and Pondicherry where, between the city of Chennai and south of Nagapatinam, more than 7800 people were killed[35].

The damage was greatest in the first hundred metres from the shore, where small settlements were washed away. The primary cause of loss of human life and property has been attributed to the intense overcrowding on the coast[35]. This was illustrated by a Wildlife Trust of India survey of 1500km of affected shoreline, which showed that throughout this length, coastal zone regulations had been violated, with an average of at least 11,000 people occupying every square kilometre of the coast[36].

Geographical and biological factors also influenced the extent of the tsunami's coastal impact. Small differences in wave height and coastal topography resulted in large differences in tsunami inundation and associated loss of life, but wherever the shoreline rose steeply or was protected by mangroves, damage was found to be less pronounced[35].

In the state of Tamil Nadu, several accounts of the disaster of mangroves having a mitigating effect surfaced in the immediate aftermath. Professor MS Swaminathan, one of India's leading agricultural scientists and chair of a government enquiry into coastal development, reported that the tsunami did less damage to lives and property in Tamil Nadu in the regions of Pichavaram and Muthupet, which are both shielded with dense mangroves, than in areas where mangroves had been cleared or were absent[37,38].

Professor Swaminathan's research foundation (the MSSRF) have produced a report examining the effects of the tsunami on communities living within the Pichavaram mangrove wetland in Tamil Nadu[39]. The MSSRF describe how hamlets behind mangroves were physically protected from the tsunami, whereas settlements located on or near the beach, and therefore not protected by mangroves, were totally devastated. It seems that mangrove forest reduced the impact of the tsunami by reducing the velocity of the incoming waves (due to friction created by the dense mangrove forest), and by distributing water among the canals and creeks of the mangroves, thus decreasing the level of inundation[39]. A press report from Point Calimere wildlife and bird sanctuary (a Ramsar site), in Nagapattinam district, Tamil Nadu, also indicted that mangrove forests minimized damage to this site and the surrounding region[40].

In the neighbouring state of Andhra Pradesh, WWF-India reported that mangroves and coastal vegetation helped protect the coast and saved lives. Many fishermen, for example, took shelter when the tsunami hit in the mangroves of Coringa wildlife sanctuary, in the Godavari delta, and survived[41]. Intense shrimp farming has taken its toll on the Coringa mangrove forest in recent years, denuding up to 1300 ha (5%) in the past decade[36].

These anecdotal reports have now been reinforced by analysis of satellite images taken before and after the tsunami. An international team of researchers coordinated by the Nordic Agency for Development and Ecology (NORDECO), have found that in the Cuddalore District of Tamil Nadu, mangroves and other types of coastal vegetation significantly minimised tsunami waves and protected the shoreline against damage[42]. Their findings, published in the journal *Science,* reveal that villages located behind dense mangrove stands suffered no destruction, whereas areas an equivalent distance from the shore but unshielded by dense vegetation were seriously inundated. Five other villages set among Casuarina plantations were also protected, experiencing only partial damage[42].

Large tracts of India's mangroves have been lost since the beginning of the 20th century, with one study estimating that mangrove cover has been reduced from 600,000 ha in 1953 to 200,000-300,000 ha in 1989[2]. Along the West coast alone, almost 40% of the mangrove area has been converted to agriculture and urban development[2]. Today, mangrove forests occupy an area of about 487,100 ha nationwide, with government data indicating that in most states mangrove forest cover has gained or remained unchanged since 1995. Nevertheless, large

ABOVE: *Survivors in Nagapattinum, Tamil Nadu. The majority of lives lost in India were in this south eastern coastal State.*
© FAO / A. Vitale

stretches in almost all mangrove areas in the country are in severely degraded conditions, having reduced or negligible vegetal cover[2]. Pressure on mangroves comes from overexploitation as a source of fuel and fodder, and conversion to agricultural, aquacultural and industrial purposes[2].

157,000 hectares of land is currently used for shrimp farming in India[43], and although much of this does not take place in mangrove areas (5% according to one survey[44]), shrimp farming was still an important cause of mangrove loss in the 1990s[10].

Andhra Pradesh is the national centre for both shrimp ponds and hatcheries and in 1999 there were 84,300 ha of ponds in the State[45]. In the Godavari delta, 14% of shrimp ponds have been constructed on mangrove areas, and shrimp farming was responsible for approximately 80% of mangrove conversion to other land uses in the decade to 2000[45]. Across the State, the loss of about 2,838 ha of mangroves has been attributed to shrimp farming[46].

Afforded greater protection under Indian law, mangrove cover in Andhra Pradesh has, however, managed to increase in recent decades by almost 4,000 ha, from 21,727 ha in 1986 to 26,712 ha in 2004[47]. Despite the growth in mangrove forest cover due to restoration efforts and natural regeneration, it is important to note that simultaneous erosion and degradation caused by other land use activities such as aquaculture have resulted in the loss of 3,150 ha[47].

In Tamil Nadu, mangrove forests are relatively sparse and patchily distributed, lining just 62 miles of the 620-mile State coastline[48] and amounting to 2100-2300 ha – 0.5% of the country's total mangrove area[36]. Mangrove forests in the State are in various stages of degradation with only about 1000 ha considered to be 'dense'[36].

BELOW: *The Sri Lankan coast, between the towns of Hambantota and Trincomalee, after the tsunami struck.*

'It is definitely clear that some mangroves were damaged,
but it is also clear that they helped prevent further damage in areas where they still exist.'

A.H.M. Fowzie, Sri Lankan Minister of Environment and Natural Resources[49]

Sri Lanka

The Eastern and Southern coasts of Sri Lanka were some of the areas most heavily impacted in the region with waters sweeping inland by as much as 3km in places. Severe damage was inflicted on coastal communities in 14 districts, with at least 31,000 people killed and more than 500,000 displaced from their homes[50].

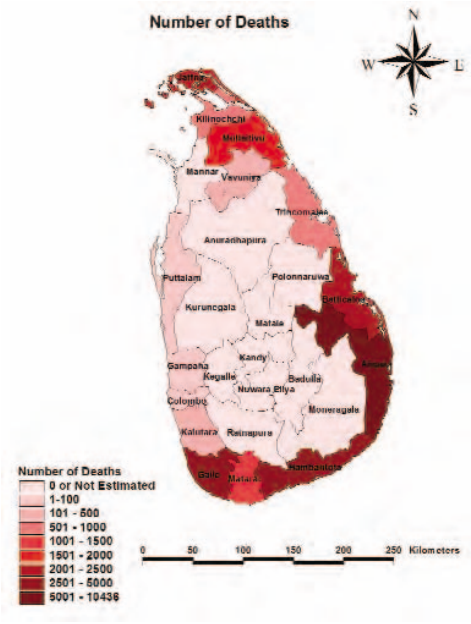
Preliminary reports and surveys carried out by the IUCN indicate that coastal areas with dense mangrove forests suffered fewer losses and less damage to property than those areas in which coastal forest ecosystems had been degraded or converted to other land use[51]. The IUCN highlight the example of two coastal villages in Southern Sri Lanka. One – Wanduruppa – was surrounded by degraded mangroves and suffered 5,000 to 6,000 casualties, whereas in the village of Kapuhenwala, which is surrounded by 200 ha of dense mangroves and scrub forest, the tsunami killed only 2 people – the lowest number of fatalities in any Sri Lankan village[51].

Hermantha Withanage, executive director and senior environmental scientist of the Centre for Environmental Justice in Sri Lanka, reported the same: in areas where mangrove forests and other coastal vegetation were present, the damage from the tsunami was reduced[52]. Where vegetation had been removed, or the shoreline encroached upon by hotels and housing, the damage was apparently much worse[53]. Also, canals linking lagoons to the sea seem to have funneled water inland and caused further flooding[53].

A further study has since emerged corroborating these preliminary findings[54]. In January 2005, a group of researchers conducted post-tsunami surveys in 24 mangrove lagoons and estuaries along Sri Lanka's south-west, south, and south-east coasts. These districts were heavily impacted and suffered more than 80% of the total Sri Lankan death toll. Their results clearly show that where mangroves did occur, they offered protection and were themselves largely undamaged, with damage limited, at most, to the fringes. However, mangroves that had suffered from "cryptic ecological degradation"* suffered severe damage and their protective properties were diminished[54]. Other coastal plant species were also found to have survived the tsunami waves and the researchers recommend that these, along with mangroves, should be used to reconstruct a vegetative barrier against future tsunamis and extreme weather events[55].

An environmental impact assessment performed jointly by the Sri Lankan Ministry of Environment and Natural Resources and the United Nations Environment Programme (UNEP) also found evidence that in areas with healthy mangroves and coral reefs, the impacts of the tsunami were significantly reduced[56].

Less than 10,000 hectares of mangroves exist along the coast of Sri Lanka. These areas are patchily distributed and are diminishing at a rapid rate. Puttalam district on the west coast, with over 2,000 hectares, has the most extensive mangroves. However, up to half of the mangrove forests in Western Sri Lanka have been developed by private investors, especially into shrimp farms[56].



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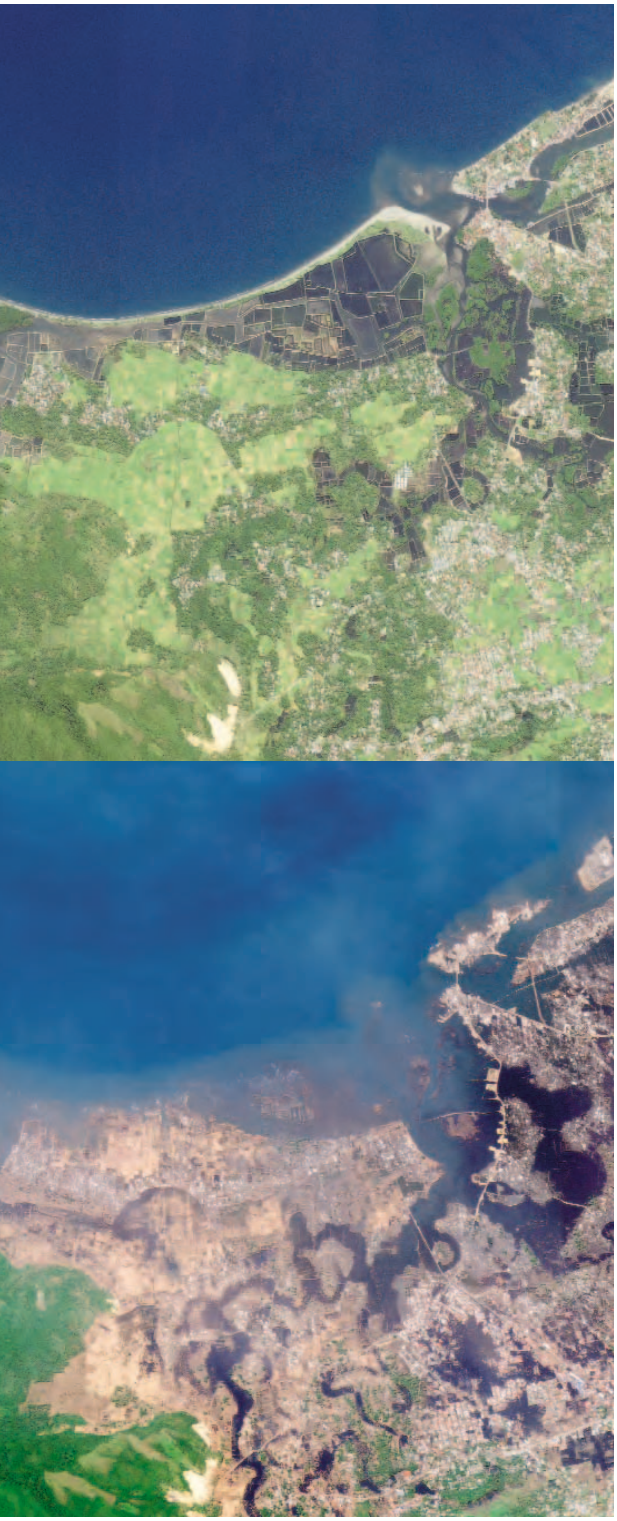
* Cryptic ecological degradation: when non-mangrove vegetation begins to dominate a forest of true mangrove species with no change in area. The fact that subtle changes in species composition had a profound impact on the damage the tsunami was able to inflict, makes clear that the loss of mangroves will dramatically increase the vulnerability of coastal areas[4].



ABOVE: *Western Banda Aceh. Following the tsunami almost all of the buildings in the town were destroyed along with all of the shrimp and fish ponds (tambaks). These occupied more than 35,000 hectares of former mangrove habitat.*

IKONOS image © CRISP 2004

Indonesia

The northern tip and western coast of Aceh province, on Sumatra Island, is very close to the epicentre of the earthquake which generated the tsunami, and consequently suffered destruction on a massive scale[57]. More than 130,000 people lost their lives in Aceh and Nias Island, while, a year on from the disaster, some 230,000 are still displaced[58].

A preliminary assessment of the impacts of the tsunami on the ecosystems of Aceh was carried out by the Kuala Lumpur-based Global Environment Centre at the request of the Indonesian Ministry of Environment[57]. The GEC found that the original mangrove forests around Banda Aceh, the capital of Aceh province, were cleared during its development, and converted to shrimp ponds (it has been estimated that there were 36,597 hectares of fish/shrimp ponds[59]). When the tsunami hit Banda Aceh, houses built on land that in the past had been sheltered by mangroves were destroyed, and hundreds of hectares of shrimp ponds were swallowed up by the sea[57]. Some pockets of mangroves had survived development, but these were too small to protect the nearby houses[57].

It is uncertain what would have been the situation in Banda Aceh if the mangroves had not been destroyed. However, five villages 100km to the Southeast of the city were saved by the extensive mangroves in that area[60]. Also, it has been claimed that Simeuleu Island, which is only 41 km from the epicentre of the earthquake, was saved partly by its substantial mangrove cover, coral reefs and seagrass beds, and suffered only four deaths in the disaster as a result[25,60]. Reports from eyewitnesses on Simeuleu Island state that no wave penetrated the mangrove forests, and instead the water level increased gently "like a rising tide"[60].

However, in the area of Ulee Lhee, close to Banda Aceh, not even dense, healthy mangroves were capable of withstanding the tsunami, such was the force of the wave[61]. Prior to the tsunami there was 10 hectares of relatively healthy mangroves at the site but the tsunami did not leave a single tree standing – they were all uprooted and carried inland by the waves, and were found in residential areas up to two or three kilometres away[61].

Indonesia has over 3 million hectares of mangroves, according to the FAO's most recent estimate – the largest mangrove area (30% of the global total) of any country. However, Indonesia also accounts for the loss of over 1.1 million ha of mangrove forest since 1980[62]. Between 1960 and 1990, 269,000 hectares of Indonesia's mangroves were converted to shrimp ponds[63].

Detailed data regarding wetland ecosystems of Aceh is scarce compared to other regions of Indonesia, partly due to the security situation in the Province. It is known, however, that Aceh's mangroves have declined in recent years, in part due to pressures of coastal shrimp pond development. Other threats include mangrove cutting for traditional use and extraction by licensed operators, and development of housing[61].

Wetlands International estimated that in 2000, only 30,000 ha of mangrove forest in Aceh could be considered to be in good condition. Damaged mangrove covered 25,000 ha, and mangrove in moderate condition was distributed over 286,000 ha[61].

The widespread conversion of mangroves to alternate uses in Aceh, and elsewhere, reflects a general lack of understanding of mangrove importance[61]. Estimating the economic value of services and goods supplied by mangrove ecosystems is difficult, and this may partly be why mangroves have been so frequently underrated. However, according to the Millennium Ecosystem Assessment of the United Nations Environment Programme: "Intact tropical mangroves, coastal ecosystems that are nurseries for fish, natural pollution filters and coastal defenses, are worth around $1,000 a hectare. Cleared for shrimp farms, the value falls to around $200 a hectare."[64]

Thailand

The worst affected area in Thailand was the central Andaman coast, between Phang Nga and Krabi, with Phuket at the centre. In recent years this region has seen a development boom along the coast[65]. The destruction caused by the tsunami was very localized, varying from total destruction to superficial damage[65]. Locations that were worst hit showed several common characteristics. They tended to be badly planned human settlements (both tourist developments and fishing communities), built close to the shore, on flat, low-lying land, and in wide exposed bays with no coral reefs[65]. They were also areas with no prior experience of similar events (typhoons, hurricanes), and therefore had no warning systems in place, and had poorly designed buildings when it came to withstanding a powerful wave[65]. Many of the tourist developments in Phuket, Phang Nga and Krabi that were badly affected were built on what were originally forest reserves[25].

In Phang Nga, the most affected province in Thailand, large mangrove forests significantly mitigated the impact of the tsunami, providing protection to the inland population[66]. As a result, the mangroves suffered damage on their seaside fringe. Coastal areas of Phang Nga, which were unprotected by mangrove forests, were severely impacted[66]. The main town of Krabi also seems to have been protected by estuarine mangroves[67].

In 2001, Thailand was the world's leading producer of farmed shrimp, but this has come at a substantial and negative environmental cost. Between 1975 and 1993, mangrove cover virtually halved, from 312,000 to 168,683 hectares[68]. The rate of deforestation has slowed recently, but in the mid-1990s the annual loss was estimated to be around 3,000 ha per year[69]. Recent studies suggest that 50-65% of mangrove loss since 1975 is attributable to shrimp farming[68].

Mangroves cover an area of around 180,000 ha along Thailand's Andaman Sea Coast – more than 70% of mangrove forest in the country. Changes in mangrove area in the six tsunami-affected provinces have been due mainly to the growth of the tin mining industry, construction of fishing port facilities, and urban/community development[70].

In recent years, the rapid growth of urban and community development has been the most controversial issue in coastal areas of Thailand's Andaman coast. However, information on the status of mangrove areas and deforestation trends in fast developing areas of Krabi, Phang Nga and Phuket is scarce[70].

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BELOW LEFT: *This image from 1973 shows the coastal area of Southern Thailand with mangrove areas.*

BELOW RIGHT: *By 2002 much of the coastal ecosystem had been converted to intensive shrimp cultivation, new infrastructure and construction of new dykes.*

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DAMAGE TO SHRIMP AQUACULTURE

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Shrimp farming technologies: from hatcheries to farms

Shrimp hatcheries (see above) breed adult shrimp (*broodstock*) and raise juvenile shrimp in tanks from the resulting eggs. Hatcheries produce shrimp *postlarvae* (young shrimp with all the characteristics of adults) or *nauplili* – the first larval stage in shrimp development – which they sell to farms. Large shrimp farms maintain their own hatcheries and sell nauplii or postlarvae to smaller farms.

Juvenile shrimp are grown to a marketable size on shrimp farms in growout ponds, which takes between three to six months. Shrimp are harvested using nets or by draining the ponds.

© Mohamed Shariff

The marine fisheries and aquaculture sector bore the brunt of the tsunami, with over 111,000 fishing vessels lost or damaged, and 1.7 million units of fishing gear destroyed[71]. FAO damage assessments put the material losses of fisherfolk across the Indian Ocean at US$520 million, although this does not include indirect losses from lost earnings and impacts on associated industries, such as processing and marketing[71]. There were over 60,000 fatalities in the fisheries sector – around one quarter of the total death toll[72].

Tens of millions of people live in coastal communities in India, Indonesia, Sri Lanka and Thailand. The majority of these people are poor and highly dependent on coastal fisheries, coastal and marine habitats, aquaculture, agriculture and forestry for their livelihoods, income and food security. In Aceh Province and on Nias Island, for example, fisheries provide employment to over 94,000 people, or nearly 20% of the total coastal population; whilst in Sri Lanka, 250,000 people work in fisheries, with around one million people in households dependent on the sector[72].

The restoration of people's livelihoods following the tsunami is clearly a primary concern – and indeed money for new boats and equipment has flooded in from many donor states, agencies and NGOs. However, the resources relied upon by coastal communities were in many cases in a dire state prior to the tsunami; fish stocks in the region are dangerously over-fished, with some plummeting by 90% since the 1970s[72,73]. Unsustainable aquaculture practices have also taken their toll: destruction of mangroves has left coastlines vulnerable to flooding and erosion and depleted fish stocks, and pollution has reduced the productivity of coastal habitats and arable land[72].

Rehabilitation must not return fisheries and aquaculture to their previously unsustainable state. An opportunity exists to redress past mistakes and invest in fisheries and aquaculture practices that are environmentally, socially and economically viable, sustainable in the long-term, and truly beneficial for the impoverished and vulnerable coastal communities that have suffered most from the tsunami's impact[72,73]. The United Nations Environment Programme have warned that "a return to environmentally damaging practices such as rebuilding intensive fish and shrimp aquaculture systems may well be a mistake", and recommended instead that governments and local communities consider restoring traditional, low impact forms of fish and shrimp farming[66].

Worryingly however, there are already reports of fishing fleets in Aceh and elsewhere being rebuilt even bigger than before, creating an excess of fishing capacity, and inevitably, further overfishing[74]. It seems shrimp ponds, too, are being reconstructed without setting aside land for mangroves and other coastal vegetation, and in some cases the Indonesian government has even given newly damaged coastal land to developers to create new shrimp farms[75].

India

In India, commercial-scale shrimp farming started gaining roots during the mid-1980s. It was a relatively late start, as by this time shrimp farming was well established in most neighbouring Asian countries. The boom period for the shrimp aquaculture industry in India started in 1990, but this was followed in 1995-96 by bust, with the large-scale outbreak of white spot syndrome, a highly lethal and contagious disease of shrimp[43].

Tiger shrimp (*Penaeus monodon)* dominates Indian aquaculture production. Today, an estimated 157,000 hectares of land is used for shrimp farming, with an average production of 100,000 tonnes of shrimp per year[43]. The State of Andhra Pradesh is the national centre for both shrimp ponds and hatcheries and in 1999, there were 84,300 ha of ponds in the State (more than half the country total)[45].

In 2002 – 2003, Andhra Pradesh was the leading producer of farmed shrimp, accounting for over 47% of India's total, followed by West Bengal (26.3%), Orissa (11.0%), Kerala (5.73%), Tamil Nadu (5.3%) and Karnataka (1.6 %)[43]. Presently, about 280 shrimp hatcheries have been set-up in coastal States, and of these, 148 are located in Andhra Pradesh, and a further 73 in Tamil Nadu[43].

Almost all shrimp produced in India are exported – to Japan, the EU and USA. In 2004-5 (April-March) frozen shrimp was the largest item in terms of value, contributing 63.50% of the total value of marine product exports (worth a record total of US$1.48 billion)[76]. Farmed shrimp contribute about 50% to total shrimp exports, with wild caught shrimp making up the remainder. The shrimp aquaculture industry provides direct employment to about 0.3 million people, and indirect employment to about 0.6 – 0.7 million others[43].

Estimates of the damage inflicted on the aquaculture sector by the tsunami vary, but a joint FAO/NACA report from March 2005 found that 5,753 aquaculture (mostly shrimp) farms and hatchery facilities had been damaged[77].

In the State of Tamil Nadu, losses to aquaculture were estimated at around US$1.5 million, including 120 ha of small-scale shrimp farms in Nagapattinam and Karaikal districts, and 11 hatcheries[77]. Nagapattinam has the largest concentration of shrimp farms in the State with 996 farms in an area of 2384 ha[78]. The industry is rapidly increasing in the district but it escaped the wrath of the tsunami with only marginal losses[78].

In the State of Kerala, at least 14 small-scale shrimp hatcheries in four districts (Kollam, Alleppey, Ernakulam, and Kannur) were damaged. Hatcheries in Andhra Pradesh were largely unscathed, however, except for in Thupilipalem, in the Nellore District[77].

In total, the FAO estimate that almost 5,000 hectares of shrimp farms were affected, mostly in Kerala, with smaller areas affected in Tamil Nadu and Andhra Pradesh[77]. A provisional assessment by the Indian government put losses to shrimp farms at US $3.3 million[78].

However, in contrast a survey by a team of scientists from the Indian Council for Agricultural Research (ICAR) found that in one district (Ernakulam) of Kerala, 24 shrimp farms, covering 8,577 ha, were damaged in addition to 4 hatcheries[78]. In Kannur district, 73 ha shrimp farms were found to be affected, and one hatchery severely damaged. A further 7 hatcheries in Kollam and Allepey districts also sustained damage[78].

The ICAR report concluded that in Tamil Nadu – the State worst affected by the tsunami – shrimp aquaculture had only suffered minimal damages and loss in the context of damage to the fisheries sector. Moreover, shrimp hatcheries were closed, as they had completed their second harvest of 2004, and had not begun their stocking operations (this normally starts in late January or early February)[78]. This minimised the immediate effects on hatchery output, but future shrimp production was impacted by seawater inundation and siltation of farms and damage to pump-houses and other infrastructure[79].

The massive loss of fishing boats and gear also badly impacted on shrimp hatcheries, and by extension on shrimp farm production, as fishermen were not able to venture out to sea and collect female shrimp (brooders) needed to produce juvenile shrimp (post-larvae)[79]. In Tamil Nadu, for example, 57,000 small boats were damaged or destroyed and over 150,000 nets were lost or destroyed. In neighbouring Andhra Pradesh, 1,362 boats and 40,000 nets were lost and more than 11,000 boats damaged[79]. The escalated cost and short supply of brooders affected many hatcheries (more than 32%) which had to shut down production. Broodstock imports are restricted by the Indian government due to the danger of viral disease[79].

The hatchery and fishery segments of the Indian shrimp producing industries suffered much greater damage than the processing or farm segments, with damage sus-

BELOW: *Shrimp farm ponds, Tamil Nadu, India.*

RIGHT: *Fishermen in Nagapattinum, Tamil Nadu, India, who lost their homes, boats and livelihoods salvage what they can.*

tained by 10% to 25% of India's hatcheries, according to AJ Tharakan, president of the Seafood Exporters Association of India[80].

Both broodstock catches and hatchery production decreased in the first half of 2005 by 16% and 25%, respectively[79]. Figures for production of farmed *P. monodon* for the first 6 months of 2005 show a smaller drop of around 5% in comparison with the equivalent period of 2004 – from 37,329 tonnes between January- June 2004 and 35,451 tonnes between January- June 2005[79].

The long-term impact of the tsunami on the shrimp industry as a whole is difficult to ascertain. Indian hatcheries project that their 2006 production of *P. monodon* PL will be 36.4% below their 2004 production[79]. However, this estimate is not corroborated by the much lower projected 12.5% decline in wild-caught broodstock catch, the input used by hatcheries to produce postlarval *P. monodon*. It is also contradicted by the 6.7% decline in production forecast by shrimp farms[79].

In December 2004, the US implemented anti-dumping tariffs on imports of cheap shrimp from several Asian and South American countries, including India, to protect its domestic shrimp industry. However, following the tsunami, the damage inflicted on the Indian and Thai shrimp industries was reviewed by the US International Trade Commission (ITC) in order to determine whether there were sufficient grounds to warrant lifting the punitive tariffs.

The US ITC completed their investigation in November 2005, ruling that that the tsunami had only a modest impact on production potential, and had not significantly restricted the ability of producers in India to produce and export shrimp. It was agreed that the trade tariffs should remain in place[79].

In India, the development of shrimp farming, despite generating substantial financial benefits, has resulted in a number of negative environmental and social impacts. These include destruction of mangroves and other coastal wetlands, water pollution, salinization of drinking water wells and paddy fields, depletion of wild fish and shrimp stocks, and loss of access to land for local people (for farming, grazing and fishing)[44]. These negative impacts have occurred particularly in areas with the highest concentrations of shrimp farms – for example Thanjavur and Nagapattinum districts in Tamil Nadu, and Nellore and Krishna districts in Andhra Pradesh[44].

In Tamil Nadu, for example, where shrimp farming earns the State just under US$40 million annually[81], the industry is nevertheless a deeply unwelcome presence for many local people. Out of 1,800 farms dotted along the coastline only 432 have a valid licence[82] and, despite government orders for the removal of 396 farms, they continue to function[83]. Groups representing local fishermen and inhabitants blame shrimp aquaculture for the destruction of coastal habitats such as mangroves, pollution of groundwater supplies and salinization of arable land, and are calling for removal of all shrimp farms from Tamil Nadu coastline[82,84].

India's coastline is nominally protected by the coastal regulation zone (CRZ) provisions in the Environmental Protection Act. However, the rules are widely ignored by State governments to allow major developments (e.g. aquaculture, tourism) that have destroyed the natural protection, such as sand dunes and mangrove forests[44,84].

Thailand

Nearly 500 fishing villages on Thailand's Andaman coast were damaged or completely destroyed, and nationwide the tsunami damaged or destroyed 5,397 fishing boats (75% of which were small traditional craft)[85]. Thailand's shrimp farms fared substantially better, however, with just 30 hectares impacted[85]. Despite being one of the world's leading producers of farmed shrimp, with many tens of thousands of shrimp farms in operation, relatively few of these are located on Thailand's Andaman Sea coast (most are located on the Gulf of Thailand coast). Furthermore, those that are present in the tsunami-affected provinces are located some distance from the shoreline and so escaped damage[79].

However, Thailand's largest and highest quality shrimp hatcheries (1300 in total) are located in the 6 provinces directly affected by the tsunami. In 2004, hatcheries on the Andaman coast represented 60% of the country's overall postlarval production[79]. The proximity of these hatcheries to the shore meant that they sustained severe damage when the tsunami struck, which has since led to a reduction of around 35% of Thailand's postlarval production capability, according to the Thai Shrimp Association[79]. The TSA estimate total damage inflicted by the tsunami to the shrimp industry to be about US$60 million, including damage to farm property, loss of broodstock, postlarvae (PL), and loss of opportunity[79].

Thai government and TSA officials originally estimated that hatcheries could be rebuilt in around 6 months. However, this has proven impossible in many cases due to a variety of factors – mostly a lack of available funds (exacerbated by the fact that many hatcheries were uninsured) – and the TSA now predicts that complete rebuilding and resumption of hatchery activities will not be complete until the end of 2007, with production not expected to return to pre-tsunami levels until 2007 at the earliest. Hatcheries have predicted a 10.7% decline in production of shrimp postlarvae from 2004 to 2006[79].

Figures from the six months following the tsunami show that hatchery production was reduced by around 40% nationally, and by 60% in the 6 provinces hit by the tsunami. In Phang-nga, for example, which was especially badly affected, hatchery production was reduced by over 95%[79].

Thai shrimp farms are dependent on hatcheries for their supply of juvenile shrimp (postlarvae), and a reduction in hatchery production therefore has downstream impacts for shrimp farms and processors. Thus, despite avoiding the direct impact of the tsunami, the effects of the waves have nevertheless been felt indirectly at the farm level. Shortages of postlarvae were felt in the first quarter of 2005, increasing its price by 30%, and the TSA claim that shrimp farms continued to suffer from the limited supply of PL for the rest of the year[79].

BELOW: *Thai shrimp farms escaped virtually unscathed from the initial wave, but the destruction of many hatcheries resulted in shortages of postlarvae and reduced shrimp production in 2005.* © EJF

In April, the FAO estimated that the tsunami damage would drive down Thailand's shrimp exports by 75,000– 80,000 tonnes in 2005[86]. Data from the Thai Department of Fisheries shows that in the first half of 2005, quantities of farmed shrimp produced decreased by 27% compared with the equivalent period last year, from 140,449 tonnes to 102,572 tonnes[79]. Production figures for the latter half of 2005 were not available at time of writing, but Somsak Paneetatyasai, president of the Thai Shrimp Association, claimed in November 2005 that total shrimp production was expected to shrink by 10% over the whole year due to the tsunami's impacts[87]. It is worth highlighting, however, that from examination of past production figures for Thai farmed shrimp, annual fluctuations in excess of 8% are not uncommon[79].

Thai farmers are predicting a 5.6% decline in production during the period 2004-6 – a much lower figure than that predicted by hatchery owners, whilst processors forecast an increase of 3.3% over the equivalent period[79].

As in India, the US International Trade Commission reconsidered the imposition of anti-dumping tariffs levied against imports of Thai shrimp, in light of the impacts of the tsunami on the Thai shrimp industry. Ruling that any declines in production following the tsunami were likely to be modest, as in India, the ITC concluded that anti-dumping tariffs should be left in place[79]. In fact, Thailand managed to increase total exports to the US between January-September 2005 to 111,000 tonnes, a 32.5% increase on the previous year, despite the tariffs and the impacts of the tsunami[88].

Indonesia

In Aceh Province, the fishing and aquaculture industries were the most severely affected of all economic sectors, with total damage and losses estimated at US$511 million[89]. Two thirds of all fishing boats were damaged, destroyed or lost and over 20,000 hectares of fishponds were affected[89]. Those dependent on fisheries and aquaculture made up a high proportion of human casualties, with 10-20% of fishermen perishing when the waves struck[90].

Aquaculture forms a vital part of the livelihoods of many coastal people in Aceh. The main farming system is the brackishwater pond – known locally as a tambak – which, prior to the tsunami, covered 47,000 ha[91]. The main species reared are milkfish and shrimp; in 2003, around 6,100 tonnes of milkfish were produced, mainly for domestic

BELOW: *Two thirds of all fishing boats in Aceh were destroyed, damaged or lost, and total damage to the fisheries sector is estimated to be US$511 million.*

consumption, together with an estimated 10,300 tonnes of shrimp, destined for export markets (primarily Japan, but also the EU, US and others)[91].

Brackishwater farming makes a highly significant contribution to the value of the fisheries sector in Aceh. National statistics give a farm-gate value of US$56.3 million, with tiger shrimp *(Penaeus monodon)* contributing the biggest proportion, providing US$41.8 million to total value[91]. MAFF/World Bank figures give the fisheries sector of Aceh a value of US$176.67 million, accounting for 3% of GDP[92]. Based on these figures, the value of brackishwater aquaculture products is therefore 32% of total fishery value[91].

Tambaks are mainly concentrated along Aceh's north-east coast. The majority of farms are small-scale (<2 ha) traditional, family-based operations, although more commercially-orientated semi-intensive and intensive shrimp farms are also present, but make up a small proportion (probably less than 20%) of the total numbers of ponds and area covered[91]. Aquaculture in Aceh was a highly significant livelihood activity for many people with at least 40,000 people directly employed in aquaculture[91].

The tsunami damaged over 20,000 hectares of fishponds, and around half of these have been severely damaged or destroyed completely. In the heavily affected district of Aceh Besar, for example, tens of hectares of ponds and canals have simply been lost to the sea. 193 of the 223 shrimp hatcheries in the province have also been extensively damaged[91].

The loss of such a vital source of income and employment is clearly an extremely serious matter for the people of Aceh. Indeed, the FAO/WFP have estimated that the 2005 output for fisheries sector expected to fall from normal production levels by 45% for marine fishing and 28% for brackish water aquaculture[90]. There has been a reduction in fish supply to local and export markets – particularly in the case of farmed shrimp, for which Aceh was a leading producer[91].

Some progress has been made in restoring/replacing damaged and lost small boats and it is expected by the FAO that much of the fishing industry can return to near normal in 2006[90]. However, very little progress has been made in restoring the aquaculture sector and the FAO/WFP predict that it is likely to take much longer to re-establish itself.

Support to aquaculture has been limited to assistance with cleaning of small canals and some ponds. Around 5000 ha, or 25 percent of the ponds, are reported to be back in production, although less than 10 percent are operating at pre-tsunami levels[89].

Further investment in rehabilitation of ponds, canals, and hatcheries is required[89], and with significant numbers of unemployed in north-east coastal areas following the tsunami, there is undeniably a strong social justification and increasingly urgent need for support to rehabilitation of aquaculture[91].

However, it is vitally important that the many social and environmental problems caused by shrimp farming are rectified in any rehabilitation programs. The development of brackishwater pond farming along the north-east coast of Aceh has, for example, contributed to the loss of mangroves in the province[61,91].

In the post-tsunami reconstruction, an opportunity exists to reconsider whether investment in an industry that, on the one hand, generates lucrative, albeit short-term, profits, but on the other, is well known to have serious long-term environmental and economic ramifications, is the best long-term strategy for Aceh to move on from the disaster.

Certainly, if shrimp aquaculture is to be restored, there must be improvements made. Farms must be developed and operated in a socially, economically, and environmentally responsible manner, that brings real benefits for local people. Shrimp ponds should be located in areas that are suitable for shrimp production and in ways that conserve biodiversity, ecologically sensitive habitats and ecosystem functions[91]. There should also be clear legal title to the land, which should not be located in any existing or proposed green belt, and design and reconstruction should be done in ways that do not cause offsite ecological damage, for example salinization of agricultural lands or disruption of water supplies[91].

ABOVE: *The tsunami damaged 20,000 hectares of shrimp farming ponds in Aceh. People have taken to catching anything they can from the few remaining ponds and canals.*

PICTURED: *Huge areas of coral were killed on Simeulue Island, Sumatra, when the earthquake raised the seabed by several metres, permanently exposing reefs to the air.*

Coral Reefs – a first line of defense?

Coral reefs are vitally important coastal ecosystems, providing local communities with a range of valuable social and economic goods and services. In addition, many reports, some relying largely on anecdotal evidence, have claimed that intact and healthy coral reefs shielded coastal communities from the worst of the tsunamis wrath. In the Maldives, for example, the extensive coral reefs surrounding the islands reportedly saved lives as they caused the wave to break offshore, dissipating much of its energy[49]. Similar reports have come from the Surin island chain, off Thailand's west coast, where despite the fact that the islands were directly in the tsunami's path, very few people died, as "most scrambled to safety as the first wave exploded against the coral"[93,94].

Sri Lanka offers some of the best evidence for the protective properties of intact coastal ecosystems against aggressive waves. Surveys of the country's southwest coastline by American and Sri Lankan scientists have shown that onshore areas located behind intact coral reefs were shielded when the tsunami struck. But in areas where reefs had been destroyed by illegal mining, onshore destruction was far greater[95].

In the south-western town of Peraliya, where the research team found coral removed, a 10 metre wave surged more than a mile inland killing 1,700 people when it swept a passenger train 50 metres off its tracks. Two miles south, where the intact coral reef is protected by hotel owners as a tourist resource, the wave reached a height of just three metres, and penetrated inland 50 metres, causing no deaths. According to the study, the difference between the sites is not attributed to coastline features, such as headlands, bays or river channels, but the fact that the intact coral, just a few metres from the beach, blocked the wall of water and significantly reduced its height[95].

Sri Lanka has 68,000 ha of coral reef, with 190 species of hard coral and over 300 species of fish[66]. However, in many areas corals had been all but destroyed prior to the tsunami by the mining of coral rock for making lime and cement. Other destructive activities such as blast fishing were also ongoing, even in reef areas designated as national parks. The government rarely enforces laws against these destructive practices[66,95].

An environmental assessment of Sri Lanka, performed jointly by the government and the UNEP, also found that the most severe damage to Sri Lanka's coast from the tsunami was where mining and damage to coral reefs had been heavy in the past. In addition, vegetated coastal sand dunes were found to stop the tsunami in its tracks[56].

Elsewhere, though, the correlation between healthy coral reefs and reduced damage has not always been observed. Field studies carried out on the northwest coast of Aceh, Indonesia, where the tsunami was most ferocious, found no evidence for healthy reefs having mitigated damage on land[96]. Instead, the extent to which the waves penetrated inland was largely determined by wave height and coastal topography; they stopped only when they reached high ground, often up to 4 km inland[96]. For example, a flourishing reef in front of the village of Lampuuk did not prevent the complete destruction of every structure in the settlement, except the mosque. Similarly, the villages of Lampuyang, Lhoh, Pasi Janeng, and many others in Pulau Aceh were situated behind intact reefs, yet the tsunami left not one building standing in any of these villages[96].

Southeast Asia contains nearly 100,000 square kilometres of coral reefs, which is almost 34% of the world total. Yet, like mangroves, coral reefs are in peril – an estimated 88% of Southeast Asia's coral reefs in Southeast Asia are threatened by human activities. Their main threats include overfishing, destructive fishing practices, and sedimentation and pollution from land-based sources[97].

Shrimp farms pollute coastal waters both directly, and indirectly, through destroying mangroves and wetlands that act as natural filters. This leads to increased erosion, siltation and pollution, which can result in degradation of coral reef habitats[97].

Many of the ecosystems that were hit hardest by the tsunami were already under serious pressure from chronic human misuse. Coastal habitats such as mangroves and coral reefs have been consistently undervalued by policy makers, and thus often left unprotected. Over the past decades millions of hectares of mangroves have been converted into shrimp farms, tourist resorts, agricultural and urban land, whilst coral reefs are threatened by over-fishing, destructive fishing practices, sedimentation and pollution.

Mangroves, coral reefs, and other coastal habitats are immensely valuable, however, and provide multitudinous benefits for coastal communities. These are both direct, for example by providing firewood, fodder and serving as fishing grounds; and indirect: they serve as important nurseries and feeding grounds for many exploited marine species, and act as protective shields against storm events, as has been so vividly highlighted by the tsunami.

Responsible reconstruction and better protection of coastal ecosystems is therefore vital if coastal communities are to fully recover from the disaster, and be protected in the future. UN agencies have recommended that governments and local communities should consider restoring mangrove forests as part of the reconstruction process post-tsunami[1,66]. Many governments have now announced such schemes and are proposing better protection for mangroves in the future.

MANGROVES AND COASTAL ECOSYSTEMS POST-TSUNAMI

PICTURED: *Mangroves and coastal forest post-tsunami, Sri Lanka.*

ABOVE: *While in some areas, for example on Simeulue Island, Sumatra (above), damage to coral reefs was spectacular, many field studies have now concluded that the damage wrought by the tsunami was minor in comparison to damage caused by human activities.*

Coral Reefs

While there is some compelling evidence for coral reefs acting as a natural breakwater and protecting shorelines when the tsunami struck, they also took some of the blow, although the damage was in many cases far less than had initially been feared.

Reefs were damaged by both the force of the waves and by debris carried onto them by the backwash that occurred when the tsunami retreated. Sediment, trees, rubble, cars and other debris were dragged into the ocean, but damage was often quite localised[98].

A study of 175 sites along 435 miles of Thailand's west coast found that 60% of reefs suffered little or no damage. Just 13% suffered severe damage and scientists expect that to recover in 5 to 10 years time[99].

A different study, completed in March 2005 by the Coral Cay Conservation group, found that just 8% of reef coverage in western Thailand's Surin islands will be lost, even if all of the tsunami damaged coral dies. Encouragingly, the researchers also found that only 8 weeks after the disaster there were signs of the reef regenerating[100].

In the Maldives, surveys carried out by Australia's leading marine science agencies of 124 sites found varied but minor direct damage to coral reefs[101]. The country's reefs are still recovering from an extensive bleaching event* in 1998, caused by abnormally warm sea surface temperatures, that killed an estimated 90% of the coral. Many survey sites were found to have a light coating of sand, which is a concern as small coral recruits are extremely vulnerable to smothering and even a light coating of sand may make reef surfaces unsuitable for future settlement. A significant consequence of the tsunami may, therefore, be to hamper the recovery process[101].

Even on the northwest coast of Aceh, where the tsunami was most powerful, the damage to reefs was patchy and fairly limited[96]. Where corals were growing on sand or rubble many colonies were spectacularly overturned, but those attached to a solid substratum survived more-or-less unharmed. In fact, the researchers responsible for surveying 200km of Aceh's coastline found that in comparison to damage caused by human activities, such as cyanide and dynamite fishing, and runoff from fertilizers and sediment, the damage wrought by the tsunami was "trivial", accounting for just 5-10% of the damage observed[96].

Reefs suffered far greater damage on the nearby island of Simeleue, and India's Andaman and Nicobar Islands, because they were hit by the original earthquake as well as the subsequent tsunami. Many kilometres of shallow coral reef have been killed in these locations when the earthquake lifted the seabed by several metres, permanently exposing the coral to the air[99]. Elsewhere in India, for example the reefs of the Gulf of Mannar, damage to coral was found to be minimal[102].

Where reefs have sustained serious damage there is no evidence to suggest that they will not recover naturally. Corals damaged by cyclones and typhoons in the past have recovered without human intervention. Various engineering techniques have been proposed to restore damaged reefs, including the installation of artificial concrete and wire reefs and schemes to cement corals back into place. However, these 'quick fix' solutions are expensive and totally unproven according to the World Bank's Coral Restoration and Remediation Working Group. Instead, governments should concentrate their scant resources on other threats to reefs such as overfishing, pollution and fishing with explosives[98].

* Corals in tropical seas depend on photosynthetic single-celled algae called zooxanthelle that live within their tissues. Coral bleaching results when zooxanthelle are released from the host coral due to stress. The coral thus loses its pigment, leading to a bleached or completely white appearance.

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Mangroves

Mangroves, depending on the species, have the ability to re-sprout from broken stems and even the trunk of a tree that has lost its canopy[103]. However, as different species grow at different rates, and rates depend on site conditions, it is difficult to give a single restoration rate for mangrove forests damaged by the tsunami. In some areas, for example where El Nino events or hurricanes have destroyed mangrove stands and caused siltation, there is no or very little natural regeneration[103,104]. But under ideal conditions, and with a ready supply of waterborne seeds or seedlings (propagules) from adjacent mangrove stands, the forests can regenerate fast – for example *Sonneratia alba*, a common low shore species, can grow at up to 1.5 m per year[104]. As a general estimate, it is thought that mangrove forests can self-repair over periods of 15–30 years[105].

The extent of the damage to mangroves post-tsunami is still unclear in many cases, and it may take some time before the final impacts are known. In some areas, for example in Aceh province, poor records of mangrove status prior to the tsunami have meant that distinguishing tsunami damage from longer-term degradation due to human activities is difficult, and may have led to tsunami damage being overstated[61]. The FAO are currently engaged in a detailed technical assessment of mangroves and other coastal forests affected by the tsunami in Southern Thailand[106].

In addition to the direct force of the waves, which tore off leaves, branches, and in places uprooted whole trees, silt deposited by the tsunami may have clogged the pores of the aerial roots of mangroves, suffocating them. Changes in topography, soil salinity and the flow of freshwater from upstream may also adversely affect the mangroves and other coastal forests in the longer term[1].

In some countries, however, the area of mangroves affected was relatively minor. Over 180,000 ha of Thailand's 244,000 ha mangroves cover is on the Andaman sea coast, but only 306 ha of mangrove forest was impacted by tsunami, mostly in Phang Nga Province, representing less than 0.2% of total area[66].

In Sri Lanka, too, post tsunami impact assessments have found minimal damage. A survey of 24 mangrove lagoons and estuaries along the south-west coast – the most heavily impacted area of the country – revealed virtually no uprooted mangrove trees. At most, mangrove fringes near the water edge took all the energy and were damaged[54]. An IUCN study in Batticoloa and Ampara districts on the East coast, found that narrow mangroves stands immediately adjacent to the sea were severely damaged by the tsunami waters, but in the case of dense broad mangroves, only the frontline trees growing in the first 2-3 m were affected[107].

A preliminary assessment carried out by the government and international donor agencies in Indonesia, estimated that the economic cost of damage to the country's environment at approximately US$675 million, including damage to 25,000 hectares of mangroves. Along the coastline of Aceh and North Sumatra an estimated 48,925 hectares of forest, other than mangroves, were affected, and 30 % of this area is assumed to have been destroyed. Furthermore, approximately 300 kilometres of coastal land has been degraded or lost[108].

A later assessment carried out by BAPPENAS – Indonesia's central planning agency – estimated that approximately 90 per cent damage had been inflicted to only 300-750 hectares of mangrove forests, yielding a net loss of $2.5 million[66].

More serious damage was inflicted to mangroves on Simeulue Island, 300km southwest of Banda Aceh, and India's Andaman and Nicobar Islands, where the earthquakes lifted parts of the islands by as much as 1-2m. Consequently, mangroves, like coral reefs, are now above the high water level and are consequently dead or dying[89].

Both Simeuleu and the Andaman and Nicobar Islands are important sites for mangrove forest. Before the disaster, Wetlands International estimated that Simuleue Island had at least 1,000 ha of healthy mangrove forest (out of only 30,000 ha considered to be in good condition in Aceh Province)[61], whilst the Andaman and Nicobar Islands, with a total mangrove area of 96,600 hectares, are home to one fifth of India's total mangrove area[109]. In almost all of the Andaman and Nicobar Islands, the tsunami caused extensive damage not just to mangroves, but also coastal forests, coconut and beach forests. According to an assessment by the environment and forestry ministry, mangroves were the worst affected coastal habitat with 4,000 hectares lost and 8,000 hectares badly damaged[110].

On the Indian mainland Tamil Nadu forest department reported damage to 2,581 ha of shelterbelt, mangrove and teak plantations, with estimated loss of $1.5 million[111]. Pichavaram mangrove, one of the most important mangrove areas in the State, suffered 5-10% damage to its 1500ha from the tsunami[102]. However, observations from a MSSRF research project indicate that the tsunami has actually improved the health of the Pichavaram mangrove forest, as the influx of seawater flushed out the high level of hydrogen sulphide that had built up[112].

Mangrove restoration post-tsunami

Spurred into action by the devastating effects of the tsunami, governments across the Indian Ocean have announced a plethora of new schemes to protect and replant mangroves, and thereby attempt to rectify the widespread losses of the last decades. The Indonesian Minister for Forestry, M. S. Kaban, has announced plans to reforest 600,000 hectares of depleted mangrove forest on the west coast of Aceh and the north coast of Java over the next 5 years[113,114]. The rationale given for the project, which will cost an initial US$22 million, is to restore a natural barrier for coastal areas against future tsunamis[113,114].

The Thai government has also stated its support for mangrove restoration. In Sri Lanka too, similar sentiments have been expressed by the authorities – the Ministry of Environment and Natural Resources are looking at drawing up laws banning further destruction of mangroves and coastal dunes, and introducing legislation that forces developers to replant and build artificial reefs[75].

Malaysia has promised $25 million to replace 4,000 hectares of mangroves lost to the tsunami and to development[75]. The Prime Minister publicly acknowledged that the tsunami would have wreaked more havoc on coastal communities in the country if it had it not been for the protection of mangrove forests. His remarks stem from the fact that in Malaysia, areas where mangrove forests were intact suffered less damage, as observed by the Penang Inshore Fishermen's Welfare Association[115,116]. Nearby shrimp farms that had cleared mangroves to construct ponds were reportedly washed away[60].

In India, the government of the southern state of Kerala, where over 1924 ha of mangroves were affected[77], has pledged $8 million to supplement an existing programme to restore mangroves destroyed by cyclones[75].

LEFT: *Mangrove restoration and replanting schemes are now underway in countries across south-east Asia.*

So how likely is it that these projects will meet with success? 300,000 seedlings have already been planted near the city of Banda Aceh, but according to scientists working in the region, many have already died because they were planted too soon and in the wrong places[75].

Mangrove restoration is not a straightforward process, by any means. Most attempts to restore mangroves often fail completely, as they are poorly planned and managed and plant the wrong species in the wrong places, often in areas that have never previously supported mangroves (e.g. mudflats)[105]. Aside from the problem of these sites being unsuitable for mangrove growth, even if they succeed, planting mangroves represents habitat conversion rather than habitat restoration[105]. Thus whilst the FAO recommend rehabilitation of severely affected mangroves to help speed up the recovery process post-tsunami, they also call for caution when undertaking large-scale planting: rehabilitation and planting efforts should be undertaken within a larger framework of integrated coastal area management, and massive planting of mangroves should not take place in areas where they would replace other valuable ecosystems, such as turtle nesting grounds and sea grass beds[1].

To date, most documented attempts to restore mangroves, where successful, have largely concentrated on the creation of plantations of mangroves consisting of just a few species, and targeted for harvesting as wood products, or temporarily used to collect eroded soil and raise inter-tidal areas to usable terrestrial agricultural uses[105]. This does not equate to restoring a mangrove ecosystem, with its myriad of associated ecological functions and benefits, and is a scenario that tsunami affected countries should look to avoid.

Furthermore, replanting per se is not always the best course of action. A key error made by most restoration programmes has been the policy of replanting mangroves as the primary tool in restoration, rather than first assessing the reasons for the loss of mangroves in an area. Mangrove forests may recover without active restoration efforts, once stresses to them have been removed[105]. Rather than launch straight into massive replanting programmes, at high cost and with a low probability of success, it may be far more sensible for tsunami-affected governments to work with remaining mangroves to encourage natural re-growth and recovery. Replanting will undoubtedly be necessary in some areas that have been damaged beyond repair, but scientists stress that only if natural recovery is not occurring should the final, and very expensive, step of considering assisting natural recovery through planting be considered.

Past restoration projects have also made the mistake of tending to ignore, alienate or even exploit the people living closest to the mangrove forests. Faizal Parish, director of the Global Environment Center, a Malaysian NGO, has criticized many of the schemes proposed post-tsunami as poorly designed and managed, and likely to have a limited effect[75,117]. As newly planted mangrove trees take five years to mature it is crucial to convince local communities to nurture them until then – paid contractors certainly have no reason to carry on caring for the young shoots. Parish points to an alternative model, one where villagers are lent small sums of money to buy and rear livestock such as chickens or ducks. But instead of paying interest on the loans, they are asked to plant mangrove trees[117]. According to Parish, Indonesian villagers have planted 300,000 trees on the island of Java during the past five years, as part of a program of this kind run by Wetlands International. The loans are waived if the bulk of planted saplings survive 5 years, which gives borrowers an incentive to make sure the trees are not cut down[117].

CONCLUSIONS

ABOVE: *Recovery of mangroves and other coastal habitats is vital if local communities are to fully recover from the disaster and be protected in the future.*

In Aceh Province the tsunami struck with immense power. It seems unlikely that anything – natural or man-made – could have prevented catastrophic coastal destruction. Further away, however, in India, Sri Lanka, and Thailand, areas with dense coastal vegetation and healthy coral reefs were markedly less damaged than areas without. Initial anecdotal evidence for this has now been borne out by more detailed ecological studies and damage assessments, and the protective role played by coastal habitats has been widely accepted by governments of the tsunami-stricken nations. Massive rehabilitation programmes of coastal forest, including mangroves, have been announced and begun to be implemented.

The protective effect of mangrove forests against tsunamis is, however, relatively poorly understood. A number of factors are thought to be important: wave energy and height, bathymetry (the topography of the ocean floor), and coastline topography, which all dictate the scale of the tsunami; and also characteristics of the mangrove forest itself – crucially its width, and to a lesser extent, its height, density and species composition. It is important to note that narrow mangrove strips can have limited positive effects, and can even be negative when they are swept away, causing extensive damage to life and property, which is what occurred on the Andaman and Nicobar Islands[118].

Regardless of these ambiguities, it is an indisputable fact that loss of mangrove cover worldwide, but particularly in the tsunami-affected region, has been enormous. It would appear, therefore, that the conversion of mangrove habitat into shrimp farms, tourist resorts, agricultural or urban land over the past decades, as well as destruction of coral reefs, contributed significantly to the catastrophic loss of human lives and settlements during the tsunami.

Although the occurrence of another natural disaster of the scale of the Boxing Day tsunami is very unlikely in the near future, other threats such as cyclones, hurricanes and increased sea levels – all likely symptoms of climate change in coming years – will potentially ravage coastlines across the Indian Ocean on a far more regular basis – whereas the Indian Ocean area counted only 63 tsunami events between 1750 and 2004, there were more than three tropical cyclones per year in roughly the same area[54]. Mangroves form a life-saving shield against all storm events, and so well planned and managed mangrove restoration programmes will be key if vulnerable coastal communities are to be protected in future.

Mangroves are far more than just a 'bio-shield', however. Despite being regarded for many years as 'wastelands', ripe for conversion to shrimp ponds, agriculture and tourist resorts, it is now known that mangroves provide coastal communities with many services and utilizable products, and perform vital ecosystem functions. And yet they are still under serious threat from human activities, with rates of loss exceeding even that of tropical rainforests. Restoration and greater future protection for mangrove ecosystems damaged both by the tsunami and, far more significantly, by chronic human misuse, is essential if coastal communities are to recover and achieve sustainability.

Whether the political will expressed by governments across the Indian Ocean to preserve and replant mangroves actually manifests itself in real protection from the pressures of development, remains to be seen. Governments can be myopic when massive short-term profits, such as those that can be gained from intensive shrimp farming, conflict with long-term conservation goals. Mangroves and other coastal ecosystems are valuable resources, though, both in economic and environmental terms. Indeed it is sadly symptomatic of the way in which mangroves have been consistently undervalued that it has taken a catastrophic event of this magnitude for their importance to be widely recognized. Let us hope that governments across the world keep to their word and act to preserve these precious coastal habitats. Consumers must also now recognise their role and responsibility, for it is increasing western demand for cheap shrimp that has driven the unsustainable production of shrimp in the developing world, leading to mangrove destruction and leaving coastal populations exposed when the tsunami struck.

RECOMMENDATIONS FOR ACTION

Governments must, in the near-term, dedicate substantial additional and new resources to mangrove conservation and integrated coastal planning to ensure that:

Conservation and restoration of mangroves

- Mangrove forests damaged by the tsunami are restored, and wherever possible a green-belt re-established in coastal areas where mangroves and other coastal vegetation was cleared prior to the tsunami. Restoration of damaged shrimp aquaculture ponds back to mangroves has been carried out successfully in the past[119,120] and should be implemented in tsunami-damaged areas as new ponds are moved further inland. This would be the first major step in creating a new "bio-shield." As the tsunami demonstrated, dense, healthy mangrove forests have and will save lives and livelihoods when natural disasters strike, events which, considering the likely effects of global climate change, will be of increased frequency in years to come.
- Mangrove restoration schemes are well planned and managed, with sites and species for planting carefully selected. The creation of single-species plantations does not equate to restoring a mangrove ecosystem, with its vast array of ecological roles and benefits. Such planting should be entirely avoided.
- Expensive replanting initiatives should only be attempted in areas where there is no chance of mangroves regenerating naturally. Furthermore, restoration schemes must seek to involve the participation of all stakeholders, especially local people whose livelihoods are reliant on mangrove habitats.
- Laws protecting mangroves are enforced on the ground, in terms of licensing, concessions and punishing illegal activities, so that there is no further destruction or degradation due to aquaculture, agriculture, urban development or any other activity. Illegal clearances must be rectified and appropriate penalties applied.

Rehabilitation of shrimp aquaculture

- The reintroduction of shrimp aquaculture in areas impacted by the tsunami should be assessed within the context of a true valuation of the benefits of mangroves and other natural ecosystems, and as part of a thorough coastal zone management strategy which compares cost-benefit analyses of all potential reconstruction alternatives.
- If shrimp aquaculture is to be restored following the tsunami, it must be developed and operated in a socially, economically and environmentally sustainable manner that brings real benefits to local people.
- Past mistakes are not repeated:
  - — Farms should be located in areas that are suitable for shrimp production. No new shrimp farms should be developed in surviving mangroves or allowed to impinge on mangrove recovery. Development in other ecologically sensitive habitats and productive agricultural land should be avoided.
  - — Any new ponds must be designed and managed in ways that do not cause offsite ecological damage, for example salinization of agricultural lands, pollution of coastal waters, or disruption of water supplies.
- Traditional, low impact, aquaculture and polyculture methods should be encouraged.

RIGHT: *Restoration and conservation of mangroves will mean protection for lives and livelihoods when natural disasters strike Asia's coastline in years to come.*

Consumers and retailers

- Acknowledge the fact that the shrimp aquaculture industry is responsible for numerous negative environmental and social impacts including the destruction of mangroves, which left coastal populations exposed and vulnerable when the tsunami struck.
- Refuse to purchase or sell shrimp products without certain knowledge that they have been produced in an environmentally and socially sustainable way.
- Retailers must provide detailed labelling to show true point of origin and precise production methods.

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