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A Study of the Effects of the 2004 Tsunami on Coral Reefs and Fisheries of the Indian Ocean

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ABSTRACT

This thesis serves as a broad-scale review of the effects of the tsunami on the coral reefs and the fisheries of the affected Indian Ocean region. The main goals were to 1) use my research from a recolonization project completed May 2004 as a basis for predictive-recovery models for the coral reefs, 2) review and summarize the newly available literature of the tsunami effects on coral reefs in the Indian Ocean and 3) predict the future of the Indian Ocean fisheries based on the review of the tsunami effects on human and fishery communities, using selected species as models. It was found that although the coral reefs in the Indian Ocean were already in a state of decline, the effects of the December 2004 tsunami was not as catastrophic as originally thought. With the fisheries devastated, coral reefs of the Indian Ocean have an opportunity to naturally recover without human interference.

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INTRODUCTION

During the summer of 2004 I participated in a Study Abroad trip to Belize. On South Water Caye, I conducted an experiment to study colonization of new coral rock versus smaller established corals by fish. The experiment yielded positive results with an increase in fish diversity and quantity in the region studied. More importantly, I was able to see first hand a reef in recovery following a disturbance. The coral reefs of Belize were dramatically affected by Hurricane Mitch five and a half years prior to my arrival, (late October of 1998) so I grew to appreciate also the dramatic effects of catastrophic events in coral reefs.

Initially, this Honor's Thesis aimed to model and to predict the best means to aid natural pathways of the coral reef ecosystem during recolonization. From these models, the tolerances of the coral reef ecosystem and the roles of its inhabitants could be better understood and perhaps the reefs can be more effectively protected from natural and man-made destruction. When the Christmas 2004 tsunami struck, the world came to realize that it was one of the most destructive earthquakes and tsunamis in history. Approximately 270,000 people died, entire communities were destroyed along the ocean, including entire fishing villages in Sri Lanka and India. Suddenly my Honor's Thesis was provided a new opportunity.

Little is known about the effect of tsunamis on the coral reefs and fisheries of the Indian Ocean, so I decided to expand my recolonization project into a thesis. I expanded my research into a broad-scale review of the effects of the tsunami on the coral reefs and the fisheries of the affected Indian Ocean region scaling up from a local project to a global one.

My specific goals of this thesis were to 1) use my research as a basis for predictive-recovery models for the coral reefs, 2) review and summarize the newly available literature of the tsunami effects on coral reefs in the Indian Ocean and 3) predict the future of the Indian Ocean fisheries based on the review of the tsunami effects on human and fishery communities, using selected species as models.

OBJECTIVE 1: MY STUDY

I began my project during May 2004 when I participated in a Study Abroad Program at South Water Caye, Belize (Central America). Dr. Gary Gaston and Dr. Denis Goulet directed the project using the facilities at the International Zoological Expedition (IZE). The island is situated on a barrier reef complete with mangroves, seagrass beds, and a lagoon.

I was partnered with a fellow biology major, Gary Nash. We carried out a project to test the hypothesis: the introduction of new coral will increase fish diversity. This hypothesis seems quite relevant in Belize since the reef is still recovering from Hurricane Mitch of 1998. Also, coral reefs have taken such a beating in the past half century from man-made intrusions that most reefs around the world are in a constant state of recovery from one disturbance or another. Two species of coral, *Acropora cerviconis* (Staghorn coral) and *Diploria labyrinthiformis* (Brain coral), were moved and placed on top of another Brain coral (approximately 1.5m^3). The location of the site is approximately 120m from the tree line at the southern tip of South Water Caye in water approximately 2m deep.

For a 10 day period (May 21 to June 1), we conducted daily dives using the mask and snorkel. Initially, all fish were observed, identified, and cataloged over the first 4 days.

This allowed us to determine which fish were present. Fish were placed into three categories: frequent visitors, permanent residents, and rare sightings. Next, the new corals were introduced. As best as we could, we tracked and cataloged the new species of fish qualitatively and quantitatively over the last 6 days (Appendix I). We accumulated our data and drew conclusions. A relatively stable community of fish on the patch-reef site was present before the addition of the new coral. Upon the introduction of the new corals, a decrease in both total number of species and total number of fishes was observed. This decrease was mostly due to absence of frequent visitors. The commotion of moving the corals and our presence scared off most of the frequent visitors, the permanent residents remained.

After one week, pulverized dead Redear Herring, *Harengula humerali*, was dispersed over the site to entice fish, such as morays, from under the rock. Only the quantitative measures for permanent residents increased. The other categories of fish remained stable.

At the completion of the project, we concluded that the hypothesis was supported. Initially, a stable population was observed for the total number of species and total number of fish. Then the totals decreased while the corals were moved. Once the fish became acclimated to our presence, a steady increase in both totals, species and quantities, was observed.

Our conclusions could not be considered sound evidence worthy of establishing principles, but they gave us insight into colonization of coral by fish. We realized that global events might similarly affect reef-fish abundance and diversity.

The data had many potential errors. Undeniably, the skill and experience of the investigators introduced problems. As the experiment progressed and we accumulated more time underwater, we became more comfortable and skilled in the identification of the fish. This could explain the steady increase in totals over time. The fish were also hard to count because they were constantly moving and numerous. Additionally, many species of fish traveled in schools. Our classmates may also have been a factor. Many were carrying out experiments in close proximity to our site. This was made doubly worse since most teams were disturbing the fish on their patch reef to observe the loyalty of fish to one particular coral. Since the fish on our site were left alone, many fish may have come to our site seeking refuge.

The project had limitations, but the real value of the study lies in the fact that I gained an understanding of different roles fish play, interdependency within ecosystems, roles of corals, and local inhabitants. And I now understand how disturbances affect fish populations and how there is an on-going pattern of recovery following catastrophic occurrences.

The tsunami of December 2004 was definitely a dramatic and catastrophic disturbance and undoubtedly affected the coral reef ecosystems of the Indian Ocean region. From the damage seen on the terrestrial environment around the Indian Ocean, one would surmise that the damage to the reef should be extensive. The locations of the corals we studied in Belize revealed that corals in shallow water would be most affected by storms, and perhaps tsunamis. Therefore, any change in water depth from the tsunami could cause physical and perhaps biological damage. Corals might bleach in response to the tsunami.

Coral reef fishes in the Caribbean have survived hurricanes and tropical storms, and are adapted to such effects. Coral reef-fish of the Indian Ocean have survived similar disturbances in the form of typhoons. Therefore, fishes close to shore, like those associated with the reef, can survive after a catastrophic disturbance. Even if they did remain in shallow waters during a storm they might survive just as the fishes I saw in Belize drifted with the undulations of the water. This contentment to float with the water and not fight it was quite evident, especially on the lagoon side of the barrier reef during rising tides. The fish flowed through the channels among strong currents. The fish, and also the sea turtles, used these channels as pathways between the different sides of the reef. They seemed unaffected by the stronger currents generated by the water's movement. Therefore, as long as the fish were not beached by the tsunami, one would surmise that the Indian Ocean fish could have ridden the ebb and flow of the tsunami's water. The initial impact of the tsunami on the fish population could be negligible since very few fishes were stranded on the beach (Associated Press, 2005).

OBJECTIVE 2: REVIEW EFFECTS OF TSUNAMI ON CORAL REEFS

Three communities interact for the overall health and recovery of coral ecosystems: coral reefs, seagrass beds, and mangrove communities (Molles, 2005). Coral reefs provide people with food, medical researchers with pharmaceuticals, and ecotourism opportunities for some poorer nations like those affected by the tsunami. Mangroves help prevent erosion of sands and coastlines. Seagrass beds are the major primary producer, a nutrient recycler, and sediment stabilizer. A large seagrass bed usually supports a healthy fish population on the reef (Molles, 2005). Mangroves act as nurseries and a sanctuary for juvenile fish. The waters around mangroves are much calmer than near the reef. This calm environment provides refuge among the tap roots of the mangrove trees for fish too young to survive on the reef. Once seen as a nuisance because the associated insect population, mangroves are now being recognized as nurseries and as a buffer against strong wind and wave action (Roach, 2004).

What is known about tsunami effects?

The recent tsunami that devastated the Indian Ocean and caused death and destruction of Biblical proportions offered a unique biological opportunity. Coral reefs off the coast of Sri Lanka, one of the hardest hit countries, are some of the most ecologically diverse in the world (second only to Australia's Great Barrier Reef) (Discovery Science, 2005). How much reefs were affected is only now being determined. What is known is that the fishing villages and most of the fishermen were killed.

These coral reefs and others around the world are an indispensable component of the ocean's ecosystem. They have contended for survival against negative factors introduced by humans and natural events yearly while peoples in the proximity of such reefs have depleted the fish and the fragile ecosystem for their livelihood. Sadly, these people often fail to see the long-term impacts of their fishing practices. Furthermore, hotels devastate mangroves, critical habitats for reef health, to gain beachfront property or use other expanses of open tracts of land for golf courses. Divers decimate the reef by collecting exotic corals and aquarium fish. Natural occurrences like hurricanes, tsunamis, and weather events like El Niño contribute further to the degradation of coral reefs. El Niño of 1998 caused massive coral bleaching on a global scale and left behind dead coral and stressed ecosystems (Rajasuriya & Karunarathna, 2000).

To combat the disappearance of the flora and fauna of the reef, one needs to gain an understanding of how the reef naturally recovers, particularly, from a catastrophic event a recent tsunami. Armed with such information, governments can help protect the reef and its fish populations by education and management.

The Indian Ocean tsunami of 2004 affords the opportunity to observe and examine the recovery of coral reefs. Reefs around the world are already on the decline when the tsunami redrew the coastlines surrounding the Indian Ocean (IUCN, 2001). Essentially, nature wiped the coastline clean in some regions. By doing so, many of these reefs were placed in a perilous predicament with the sheer force of the water and the influx of debris that was as large as houses and as small as silt.

One of the most positive aspects of the tsunami is that reefs now have the potential to flourish without human interference. Most of the fishermen, all of the fishing boats, and many of the villages of some regions were destroyed. Overfishing was having a dramatic impact on reefs of the region. The governments of this region have an obligation to facilitate the recovery of the reef, and they have an opportunity now that the human effects are reduces. With the loss of fisheries and fleets along the coast, the local fishermen do not want to be near the ocean (Discovery Times, 2005). Most survivors of the physical trauma are now dealing with the psychological trauma of late last year. The reefs have a chance to recover, to recolonize.

Destruction of Coral Reefs and their Potential Recovery

Most natural damage to coral reefs can be tolerated by the corals. Corals clean themselves of sand, are protected from many diseases by mucous, and have mechanisms to combat and defend themselves against predators and competitors. Sheer forces of water can damage the more fragile branching corals like *Acropora*. Although damaged, the ecosystem can still cope with such losses (McClanahan et al., 2001). The skeletal remains of *Acropora* from Hurricane Mitch were quite evident in Belize's reefs. The seafloor looked like a "boneyard." But *Acropora* grows fast and recovers quickly, within a few years (Wallace, 1999).

When water temperatures rise during El Niño such as occurred worldwide during 1998, corals lose their zooxanthellae, the symbiotic algae that usually give the corals their colors. Harder (2001) believes that this bleaching event may not be necessarily bad since the corals will usually acquire zooxanthellae more suited for the new temperature but many corals never recover from bleaching and die. However, this is not widely accepted as true.

Corals off the island of Phuket, one of the most devastated areas by the tsunami, were found to have a higher tolerance for changes of temperature (Brown et al., 2002). However, large scale events like a pH change in the water due to industrial runoff, unsound fishing practices, and massive bleaching from other man-made scenarios cannot be survived by the reef. Many nations around the Indian Ocean have seen their reefs in a steep decline. In the Philippines, over 60% of the total area once covered by corals is gone (Spalding et al., 2001).

The initial reports following the tsunami of 2004 were grim for the fates of the corals most directly in the path of the energy (Owen, 2005). This was especially alarming when the region is considered the center for coral reef diversity and productivity is the western Pacific and eastern Indian Oceans. Over 600 species of corals and over 2,000 species of fish are found in this region. In contrast, the western Atlantic Ocean only supports about 100 species of corals (Molles, 2005). Thankfully, the more recent reports indicate that the damage from the tsunami was less than expected. Damage seems to be extremely localized but still catastrophic in some regions (Discovery Times, 2005; Coral Caye Conservation, 2005).

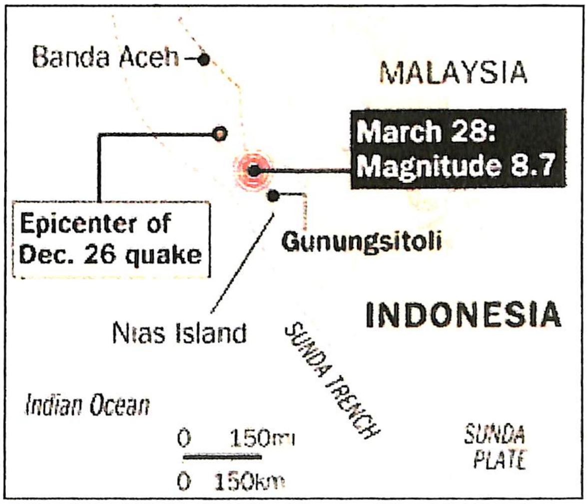
In retrospect, the focused and random damage of the tsunami makes sense. The initial set of waves in the wave-train (three waves) released a great deal of energy that turned over massive corals, displaced fish, and took the lives of so many people. This initial pounding, however, was not the main cause of the damage observed. The run-up from the waves and the water's subsequent regression back to the confines of the sea was to blame. Once ashore, the waves engrossed everything from automobiles and buildings to sewage and vegetation (Discovery Times, 2005). Fortunately, the run-up returned to the ocean with such tremendous force that a majority of the debris taken up was not deposited onto the corals but was carried out to deeper waters. For this reason, the turbidity over the corals was not as high as initially predicted. All the fine sediments would have overwhelmed the corals' natural cleaning mechanisms and killed the corals. The turbidity of the coastal waters returned to tolerable levels only days after the tsunami (Discovery Science, 2005).

Close examination of the tsunami event showed that all the debris washed out to sea by the first wave was only gone momentarily. The second, larger wave on the wave-train was now armed with the same debris. The people not only had to contend with the water, but also the debris within the water (Discovery Times, 2005).

The most susceptible corals to the tsunami were the shallow corals growing along the reef crest near deeper waters. Those corals were in the direct path of the tsunami energy and acted as a natural breakwater. Unfortunately, a breakwater must absorb or deflect the incoming energy (Quinn, 2005). This energy flipped and rolled many of the larger, more stable corals (Associated Press, 2005). Corals were most likely exposed to direct sunlight and the atmosphere during the troughs in the waves generated. This exposure probably was not long enough to inflict any kind of substantial damage to the corals by ultraviolet exposure and desiccation. The large coral structures, turned on their sides, cannot survive indefinitely without being in their upright position and gathering sufficient sunlight (Glynn, 1996). Scientists and volunteer divers began a campaign to right these overturned rocks within weeks of the tsunami. They would dive and right some of the corals. However, massive corals are sometimes just that, massive. The divers marked the massive corals too heavy to flip with buoys. Next, a surface team with a winch and large boom would assist the divers in righting these with as minimal damage as possible (Associated Press, 2005).

Once the tsunami rumbled over the natural breakwater and reached land, the ocean gathered cars, houses, soil, and sadly, lives. With everything one would find in fishing villages in tow, the water regressed back to the sea. This return dragged all the debris across the corals. This action caused extremely localized abrasive damage since a piece of debris could run into one coral and miss its neighbor just by chance.

Although the scientific community evidently overestimated the extent of the damage to the coral reef ecosystem of the Indian Ocean, the projections can be understood in the context of how many tsunamis the scientific community has encountered. This tsunami was one of the biggest in recorded history, the greatest during the last fifty years. At the time of the last big tsunamis (the 1960 Great Chilean tsunami caused by a record 9.5 earthquake and the Good Friday tsunami of 1964 with a 9.2 magnitude earthquake), the scientific community did not have the equipment necessary to study these underwater communities. Satellite imagery, underwater photography, SCUBA gear, and baseline data to compare the ruminants of the final state with the constructs of the initial state are very recent advances relative to the frequency of tsunamis (Anonymous a, 2004; Anonymous b, 2004). With all the factors lacking from earlier tsunami occurrences in place, this tsunami will serve as the baseline data with which all subsequent tsunami events will be compared. In this way, environmental projections can be more accurate. The National Oceanic and Atmospheric Administration (NOAA) had made tsunami models for the region. The data collected about run-up heights will help to substantiate their projections or help in their correction.



As I was completing my compilation of these data, another earthquake with a magnitude of 8.7 occurred along the same fault line (India and Sunda Plates) on the night of March 28, 2005 (USGS, 2005)(Fig. 1). This could not have occurred at a more opportune time for the peoples of the region and the scientific community. Although the data from the first major tsunami is still being analyzed, comparisons are still possible and more relevant. The earthquake of March 28th allowed the countries around the Indian Ocean to test the effectiveness of the evacuation plans and warning systems for their citizens. Now, the peoples of the Indian Ocean are much more educated about tsunamis. For instance, the Indonesians were awakened with the tremble of the earthquake and fled for higher ground before evacuation warnings were issued. This new-found fear and respect caused thousands to head inland and stay there for hours until the government explained that the danger had passed. Ironically, the second earthquake generated a tsunami to the southeast, away from the already ravaged nations (USGS, 2005). The warnings about a second killer wave highlight how little is known about predicting just when and where tsunamis could strike.

The silver lining to these two earthquakes happening very close together, both temporally and geographically, is twofold. First, the destruction wreaked by the first earthquake left the coastlines bare of inhabitants and structures. Therefore, even if the second earthquake had overwashed the coasts like the first, the death tolls and economic impacts would have been much less for the simple reason that the governments and aide organizations had not had time to invest in the reconstruction and recolonization efforts. This leads to the scientific benefit. With the chance of higher body counts and more missing persons dismissed, the data about the second "great" earthquake (Geologically any earthquake over 8.0 is considered to be "great") was free of widespread death and grief (USGS, 2005). The world got a second look at a rare event without paying the price of lives and property. Luckily, the death toll of the second earthquake was much smaller, 1,000 to 2,000 dead based on projections from the number of structures destroyed from the earthquake (USGS, 2005). A second tsunami never materialized to the level of widespread destruction.

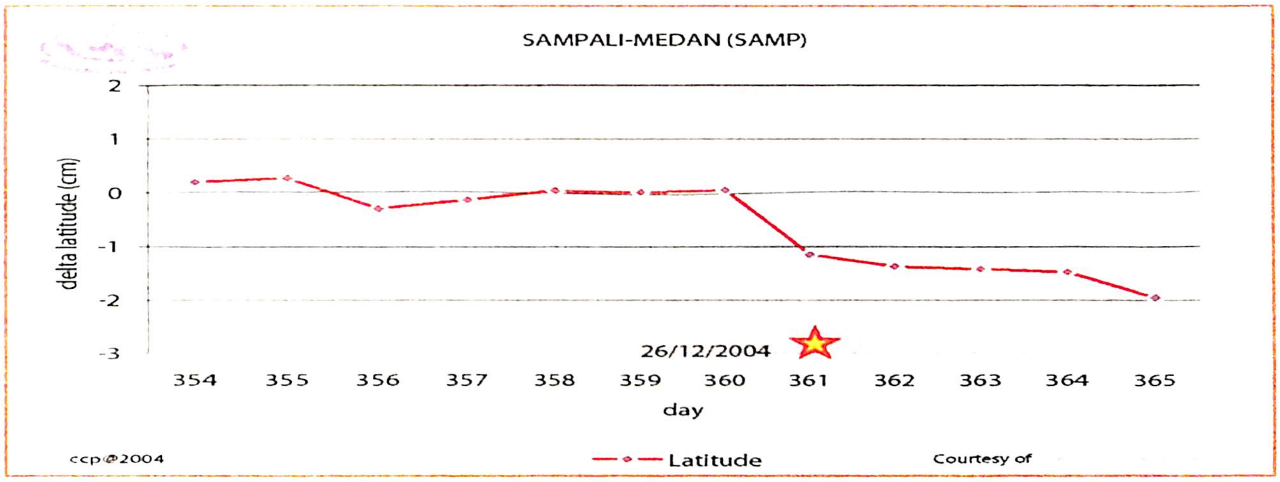
The second earthquake did not generate a tsunami. This can be explained with a simple allegory. A tsunami is not like the waves made when a rock is thrown into a barrel of water. The energy in the water does not primarily disperse in concentric circles like the rock striking the surface. Instead, a tsunami is like someone running up to the barrel and kicking it over. As a whole, the water will move in one direction. The tsunami has a directional component. The second earthquake of March 26th caused the tsunami-generating energy to go southward and away from most population centers (Discovery Times, 2005).

Mechanism for Destruction

In order to understand the scale of destruction from the 2004 tsunami one needs to understand tsunami physics. "Tsunami" is Japanese for "harbor wave." Although tsunamis have been observed for thousands of years, with the first account from the Syrian coast four thousand years ago, gaps persist in the understanding of how this phenomenon works (NOAA, 2005). Tsunamis are caused by great introductions of energy into the water column. This could be due to volcanoes, landslides, meteors, and earthquakes. The 2004 tsunami was caused by an earthquake with a magnitude of 9.0 (USGS, 2005).

All fluids, saltwater in this case, are excellent conductors of energy over long distances with very little reduction from point A to point B. In a more practical sense, this property of fluids is why brake lines are "bled" of air until only fluid remains in the line. Consequently, saltwater can house the energy from a 9.0 earthquake and pass it along to the shores thousands of miles from the source of the energy. In this case, African nations felt the effects all the way across the Indian Ocean 4,000 miles away. These effects were minimized because the Maldives, islands running longitudinally off the southern coast of India, bared the brunt of the energy on its way westward to Africa (Discovery Times, 2005).

The earthquake's epicenter was approximately 255 km (155 miles) SSE of Banda Aceh in Sumatra, Indonesia at a depth of about 30 km (18.6 miles, the same depth as the aftershock of March 28). This megathrust earthquake was caused by the subduction of the heavier India plate under the Burma plate (USGS).



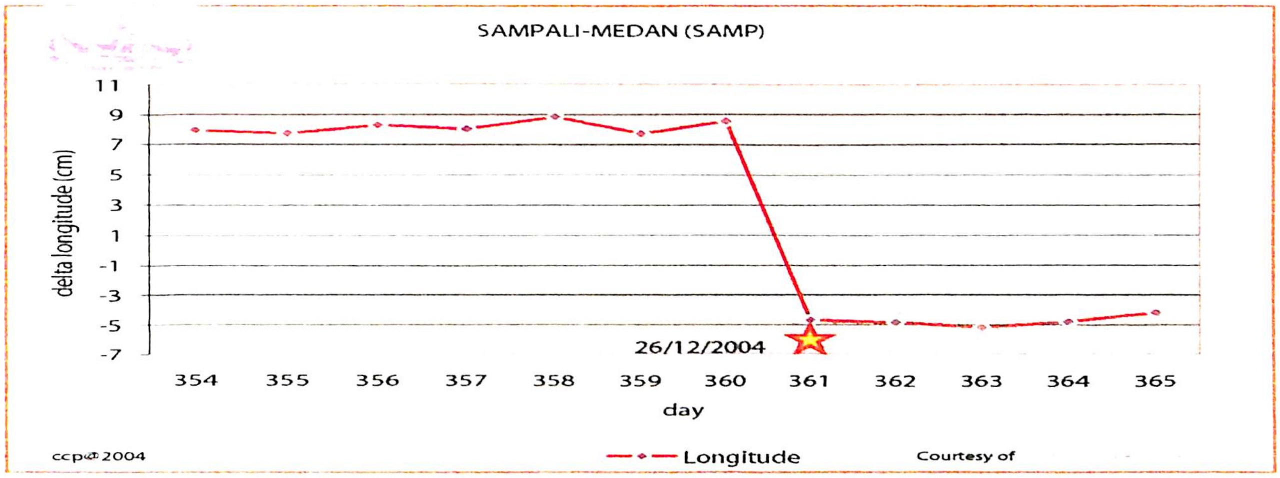


Figure 2: Subduction Distances of Tectonic Plates- shows the distances longitudinally and laterally the seafloor moved because of the earthquake that gave rise to the 2004 tsunami. Courtesy of Bakosurtan

The subduction changed latitudes and longitudes of the seafloor for 450 kilometers (Figure 2). This information is critical to predicting the direction and magnitude of a tsunami. From the geometry of the plates, the energy release caused waves to propagate east and west. The upheaval of one plate caused the upheaval of all the water above that location. The height of the upheaval is the greatest possible height of the tsunami. This limiting factor keeps earthquake generated tsunami wave heights from exceeding approximately 20m disregarding amplification due to topography (Discovery Times, 2005). The new water height on the surface produces a wave with a directional aspect. As gravity pulls on the wave, the seawater pulled from above the released plates. The leading aspect of the waves is either a crest or trough. The waves propagated east towards Thailand and Myranmar were led by a trough. For this reason, the sea receded. The uncovering of the seafloor attracts the curious to the dried, naked seascape. Unfortunately, the trough is followed by a crest. These waves form a wave-train in which they can be minutes to half an hour apart. Intuitively, the sudden increase of the wave height would be due to the law of conservation of mass. Subsequently, the change in wave height is attributed to the conservation of energy (Kowalik et al., 1991). The energy is released and is passed through the seawater as a wave moves through the deeper water at speeds around 500 m.p.h. ($\approx$ 220 meters per second) (Discovery Science, 2005). Unlike surface waves from wind action, tsunamis move the whole column and leave the surface water relatively undisturbed considering the energy in the column. However, as waves begin to reach shallower waters, the relationship from the formula below uncovers how wave height and velocity change with water depth. Figure 3 shows formula shows the same relationship graphically. Amplitude increases with $h^{-1/4}$ (derived from Green's Law) (Kowalik et al., 1993).

$V = (gh)^{1/2}$,where V = velocity, g = force due to gravity and h = water depth

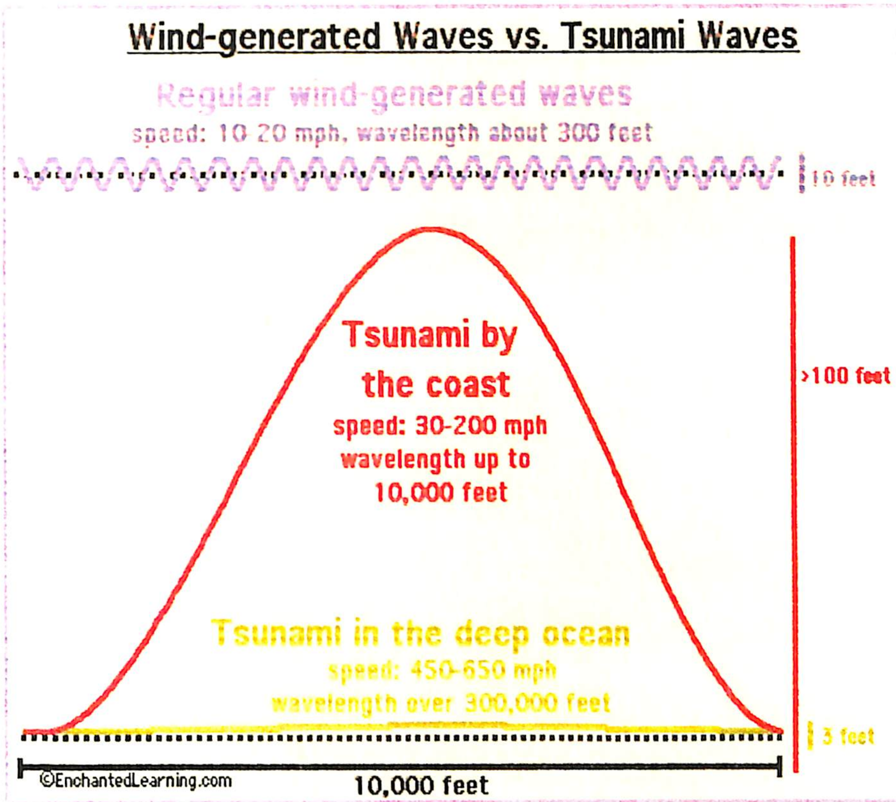


Figure 3: Wind and Tsunami Wave Profiles Enchantedlearning.com

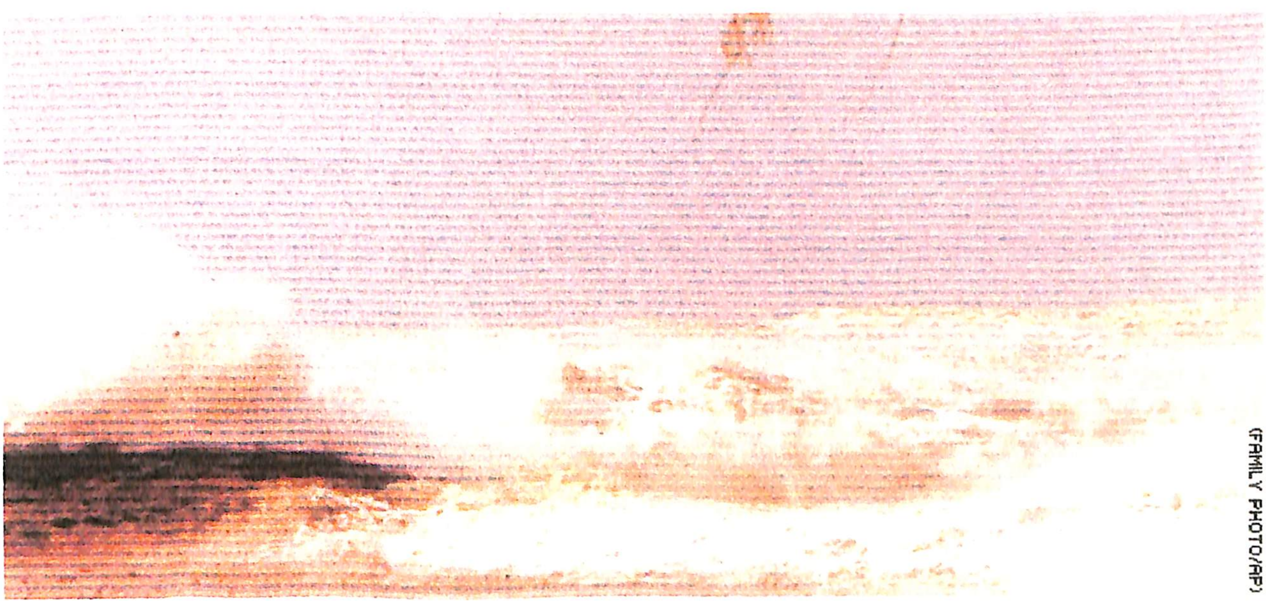
The coasts to the west of the tectonic shift did not get a tell-tale sign of tsunami like their eastern neighbors. The leading aspect of that wave was a crest. Four-thousand miles away, the same event happened to the western coast of Africa only ten hours later. The term crest refers to the energy-wave, not the water-wave. Tsunamis do not have the classic surfer's wave shape. Tsunamis usually come ashore, depending on the seafloor topography and coastline, as a wall of churning seawater rising from the ocean. Figure 4 highlights this abnormal shape (CNN, 2005).

A: Recession

B: Incoming

(FAMILY PHOTO/AP)

C: Tsunami



(FAMILY PHOTO/AP)

Figure 4: Signs of an imminent tsunami COURTESY OF KNILL FAMILY

Hurricane versus Tsunami

Damage inflicted on the reef from the 2004 tsunami was localized (Coral Caye Conservation, 2005). Most of the devastation occurred outside the confines of the sea, in coastal areas. In terms of loss of life and property damage, the tsunami is much more destructive than most hurricanes due to its sudden occurrence and the scale of its effects. In terms of destruction of coral reefs, hurricanes are more ferocious. This is most likely due to the duration of each event. Tsunamis may last a couple of hours while the wave-train pounds the coast (D. Gochfeld, personal communication). Hurricanes last days or week and can stay in one area for extended periods. Although the waves generated by hurricanes are surface waves and do not contain the magnitude force of a tsunami would, these waves constantly inflict sheer forces on the shallow corals. After days of this pushing and pulling, most of the soft corals are left disconnected from substrate and die. The affected areas and energies of both are tremendous. The tsunami's energy is so tremendous that it affected tide gauges on much of the globe. For example, gauges in Gibraltar recorded trough-to-crest heights of 3.5 cm almost thirty hours after the earthquake (Rabinovich, 2005). The earthquake that generated the tsunami was so powerful that it caused the earth to wobble on its axis.

Prediction of Reef Recovery

I was asked to assess impacts of the tsunami on reef fishes because coral reefs have proven themselves to be a critical in the overall health of the world's oceans and support diverse fish species. Along with the mangroves, seagrass beds, and lagoons, coral reefs are the breeding grounds for many coral reef fishes. Reefs and associated habitats are home to vast commercial fisheries.

Pelagic species were likely the most greatly impacted group on the reef. Small pelagic species that are found in shallower waters were most vulnerable to the tsunami. The benthic species could have found shelter in a hole on the bottom and tried to survive the momentary period of exposure. The larger species could have gone to deeper waters as the waves began to decrease the water depth along the coast. Small reef-associated fishes like the damselfishes could have found shelter in the corals. Fish not in as close proximity to the reef may not have had the opportunity to seek shelter within the corals.

Recovery of a reef is contingent upon factors like strategies of dominant species, magnitude of disturbance, environmental tolerances, biodiversity, and dynamics of a reef community (Molles, 2005). Glynn (1996) noticed that coral flats with which *Acropora* species were dominant had a slower recovery rate. Sebens (1991) hypothesizes this is most likely due to dead branches from the *Acropora* yielding an unstable substrate for coral recruitment. *Acropora* are a faster growing species with a weaker skeletal structure. *Acropora* trades structural strength for rapid growth. For this reason, branching corals suffer high mortality rates after the introduction of high stress (Obura, 2001). This was extremely evident in Belize following Hurricane Mitch (Gaston, personal communication).

We swam over a "boneyard" of broken corals from Hurricane Mitch. The bottom was white with the calcium carbonate and dead coral structures. Massive corals had also been moved leaving single corals isolated. Having seen this and read the reports about the tsunami, the breakage of the soft corals seemed significant enough to facilitate an increase in quantity of benthic species by providing more shelter and nutrients on the bottom The volume of breakage will not be so severe that the dead corals block the viable substrate for new coral development. There may be a shift in species dominance among corals since the massive corals are much more rugged. Biodiversity will at least be unaffected or may increase since the damage was either isolated or non-existent. The biodiversity could actually increase during the recovery and recolonization periods. Molles (2005) believes that abiotic disturbances may be necessary for the long-term survival of the reef.

Seagrass beds will most likely flourish as they try to recycle all the nutrients from dead organic materials introduced from the run-up. Nitrogen, usually a limiting factor in marine ecosystems, was dragged from the land or enough space was cleared to cause any major algal bloom (Molles, 2005). There have been no reports of any such blooms to date. As far as major shifts in vertebrate species dominance goes, no evidence supports any such future shift taking place. The top predators are large fishes and could have sought refuge in deeper waters. Barring the loss of a physically small keystone species like the cleaner wrasse, *Labroides dimidiatus*, on the corals, I foresee no dramatic short-term change in vertebrate species of fish due to the tsunami. If the very widely dispersed cleaner wrasse was washed away and killed, then the parasite population on fish could explode (Molles, 2005). Grutter (1999) and Bentley (1999), in separate studies, have shown that a single cleaner wrasse can remove and consume 1,200 parasites from fish clientell. Bentley also has shown that reefs with these wrasses have four times less the number of parasitic isopods as those that do not. The experimental data from a study by Bshary (2003) has shown that the species richness decreases by 24% when the cleaner wrasse was removed. On the flip-side, species richness increased 24% when the cleaner wrasses were added to the reef. The reefs Bshary studied were 2 to 6 m deep, approximately the same depth as the corals most affected by the tsunami (Bshary, 2003).

OBJECTIVE 3: FISHERIES AFFECTED

Following the 2004 tsunami of the Indian Ocean, coastlines were damaged. Fisheries were shut down, villages were leveled, fleets lost, people were displaced, and many fishermen were dead. Most of the villagers and coastal people were terrified of the ocean. If ever there were a time to try and implement a shift in the livelihoods away from fishing, now is that time. To date, governments of the affected area have failed to act on this opportunity.

The diverse communities on the reef make up a delicate balance. The reef is incredibly efficient at retaining and recycling nutrients. This is critical since the reef supports a biodiversity and primary production that rivals the tropical rainforests, which are also a nutrient poor environment (Molles, 2005). Any change in salinity, turbidity, temperature, water depth, or chemistry is easily recognized since the reef has such a low tolerance for any such changes (Turner et al., 1999). Decline of the reef causes a decline in the fish populations and fisheries.

Background of Fish Affected

One of the goals was to model loss of certain fish and predict the effects of their loss on coral reefs of the region affected by the tsunami. The fish that utilize the reef for day-to-day operations represent many different types of feeding guilds. Each interdependently plays a role in the soundness and stability of not only their species populations but also that of the corals.

Diurnal herbivores, like those in the family Acanthuridae (Surgeonfish), usually fulfill the role of cleaning the reefs by scouring the corals in search of algae that could smother the zooxanthellae and kill the coral (Jonna, 2003b). Species in the Acanthuridae family and genus *Naso* help the corals by floating over the corals while feeding. Their fecal material falls in the cracks and crevices and serves to help "promote growth and diversity of corals" (Moyle and Cech, 2000). After feeding during the day (diurnal) the fish then retire to the sanctuary of these same crevices for the night. Had these fishes been eliminated, then biodiversity would decline. The algae would not be held in check by consumption. Also, the introduction of nutrients into the cracks aids other organisms by giving them a new site to find success against competition.

Other herbivorous fish like the parrotfish (the family Scaridae) serve the reef in quite a unique way. They graze on the calcium deposits on the usually algae covered skeletal remains of dead corals. Usually feeding in large groups, providing security from predation and territorial fishes, the parrotfish can cause a significant amount of bioerosion. "It has been calculated that a single, large parrotfish, *Bolbometapon muricatum* (bump-head parrotfish), consumes approximately one cubic meter of coral skeletons per year, and turns it into fine sediment" (Choat and Bellwood, 1998). In this way, the parrotfish makes resources that are tied up in dead structures available to the food chain by providing oolitic limestone, a rock substrate composed primarily of petrified corals or the skeletons of other calcareous animals. The bioerosion is so intense that the crunching action of the parrotfish's jaws can be heard by divers. Populations of these fishes were not reduced, but if they had been I predict that a sharp decline in the quantities of large piscivores would occur. Trophically, these fish support the larger piscivores (Polis et al., 1996).

Invertebrate predators are the fish group with the most members. Their diet consists mostly of coral polyps and invertebrates. Labridae, wrasses, are a member of this group as well as many other "cleaning" species. Therefore, Labrids helps keep many invertebrate species within tolerable limits of a healthy reef. Also, Chaetodontidae, butterflyfishes are closely associated with the reef. Some species' diet is exclusively coral polyps. For this reason, their abundance is an excellent indicator of reef health. Pomacanthidae (angelfishes) are also invertebrate predators (Crosby & Reese, 1996; Ebeling & Hixon, 1991).

Omnivores like Sharpnose Puffer (*Canthigaster valentini*) and Tetraodontidae (pufferfish) are found in the waters off southeast Asia. Their diet includes algae, crabs, brittle stars, sea urchins, sea squirts, coral polyps, sponges and worms (Kuiter, 2002). They behave more carnivorous than herbaceous due to the availability of resources (Jones, 1991). Very little vegetation is available to be eaten by fishes on the reef. However, they will eat algae. These pufferfishes are opportunistic feeders. (Moyle & Cech, 2000). Without these fish, a major trophic link would be missing. Omnivores like the starry puffer (*Arothron stellatus*) help to maintain balance by consuming destructive species like the crown-of-thorns-starfish which can cause a decline in coral structures (*Acanthaster planci*) (Keesing and Halford 1992).

The piscivores like Serranidae (groupers) and Lutjanidae (snappers), eat other fish. Many of the piscivores become more active at dusk and dawn. In this way, they can get docked or dead, the numbers of fishes depends on the primary production on the reef and how much biomass it can support (Coral Caye Conservation, 2005). With the damage to the reef being minimal, the herbivore population may have an increase in response to the algal growth from either new places to grow or an influx of nutrients. Numbers of piscivores will also increase as the number of herbivores increases. These numbers should begin to decline over time due to the regression of the primary producers back to normal energy outputs without new locations or nutrients.

Biodiversity among the reef will most likely increase among the coral reef fishes. The increase in numbers fish in each group allows a competitive species to try and gain a foothold against the dominant species while so much more prey or nutrients are available. Then when the numbers of available resources declines again, the competitive species will have a better chance of success against the species that was dominant before the disturbance (Molles, 2005).

Why the Fisheries were Decimated by the Tsunami

The human population was caught off guard by the 2004 tsunami just as the Syrian victims of the first recorded tsunami four millennia ago. Modern technology offered little or no warning of the tsunami, especially to those without mass communication technology, such as the fisheries in Sri Lanka. Like the corals, human survival was mostly due to chance and location. Some places were safer than others. Areas behind a mangrove forest were buffered somewhat by the vegetation. Also, corals helped break up the wall of water (Roach, 2004). Some of the small islands were so small relative to the very large wavelengths generated that the wave just refracted around the island

(Discovery Times, 2005). This same refraction caused the wave to wrap around harbors and large landmasses. If a harbor entrance was narrow and the harbor was wide, then the energy was dissipated. Inversely, if the entrance was large and the harbor was small, then the waves were focused and had a height greater than the waves found on the tsunami-affected coast. This ability to devastate protected harbors was most likely why the Japanese fishermen chose the name "tsunami."

Oddly, the northwestern coasts of Sri Lanka, where many densely populated fishing villages were located, experienced higher wave heights than the eastern coasts which were in the direct path of the leading edge of the tsunami (Discovery Science, 2005). This phenomenon can be explained in much the same way as the harbors discussed above. The wave was refracted around the island nation and was channeled toward the northern tip of Sri Lanka. The two landmasses, Sri Lanka and India, form a funnel at their junctive. The energy reflected off the eastern coasts of India causing considerable damage there. Although it was reduced with each reflection, the energy kept moving back and forth between the landmasses all the while becoming more focused in the cone shape. The northwestern region of Sri Lanka and the southeastern coast of India make up the tip of this cone, and they felt the same focused effects as the open harbors discussed above. They experienced waves slightly higher than the tsunami-facing coasts. The high waves here aid in model building and prediction for tsunamis (Discovery Times, 2005).

Death Toll

"The tsunami caused more casualties than any other in recorded history and was recorded nearly world-wide on tide gauges in the Indian, Pacific and Atlantic Oceans."

-Anonymous USGS

A: Banda Aceh June, 2004 B: Banda Aceh February, 2005

Figure 5: Banda Aceh photos before and after tsunami. (Digital Globe)

Death tolls

Indonesia:	220,172
Sri Lanka:	30,957
India:	16,389
Thailand:	5,395
Maldives:	82
Malaysia:	68
Myanmar:	61
Bangladesh:	2
Somalia:	298
Tanzania:	10
Kenya:	1

Figure 6: Death tolls by country **wikipedia**

Total: 273,435 DEAD

* The listing includes 94,574 listed as missing in Indonesia and 5,640 in India. In addition, 3,001 people are listed as missing in Thailand and 5,637 in Sri Lanka but not included in the toll because of possible double counting.

JAKARTA (AFP) Friday, March 4

Early Predictions:

A) Nutrients

Initial projections were that the reefs would be devastated and go through a bleaching event due to turbidity and changes in coastal depths (Delay, 2004). This mass bleaching would cause a shift toward a more herbivorous fish community. This has not been the case for the reefs thus far (Coral Caye Conservation, 2005).

Since algal growth can delay or prevent coral recruitment, overfishing of these herbivorous fish could slow the recovery (Gomez, 2001). The probability of a coral-choking algal bloom was heightened by the fact the waters affected by the tsunami carried topsoil, sewage, and organic material back to the reef. This increase in nutrient levels in the water column would help facilitate an algal bloom. Obligate coral feeders like the butterflyfish are excellent biological indicators of coral health (Crosby & Reese, 1996). Investigators targeted them for insight into how the reef would react. Conversely, an increase in dead coral could cause more algae which would enhance populations of echinoderms, like sea urchins, herbivorous fish, and grazers like surgeonfish (Hixon, 1997). Apparently, the reef is not undergoing a mass bleaching event and no algal blooms have been recorded. Therefore, the reef's balance was not greatly upset by the influx of nitrogen or the tsunami as initially predicted.

B) Physical Disturbance

Sousa (1979) examined the growth and diversity of algae and invertebrates on boulders in the intertidal zone. His conclusions were relevant to this study since the boulders in the intertidal face the same type of disturbance as the massive corals affected by the tsunami.

Disturbance can drive biodiversity, and moderate disturbances can lead to increased biodiversity (Molles, 2005). The impact on the environment is contingent on frequency and intensity of the disturbance (Molles, 2005). Although Sousa's study dealt with invertebrates and algae, these organisms form the base structure of nutrient extraction from the water for the reef associated fishes. Therefore, certain species of invertebrates and algae influence the presence and overall success of fishes that feed on them.

Sousa (1979) catalogued different size boulders and their respective associated organisms. He found that disturbances are good for increasing biodiversity, but only to a point. Sousa (1979) found that larger boulders that were mainly unmoved were overrun with the dominant species of algae and invertebrates. Smaller boulders gave way to the rolling action more frequently. The rolling opened up spaces for organisms that the dominant species had competitively excluded. These openings generated by the disturbance add to the biodiversity as more rugged organisms compete for space. The smallest boulders had a low biodiversity. With more disturbances, the organisms are no longer competing for space as much as they are struggling to survive and reproduce. Therefore, disturbance increases biodiversity among the boulders until a certain threshold is reached. Then the biodiversity decreases due to the inability of the organisms to survive long enough to reproduce.

The 2004 tsunami resulted in many coral heads being overturned or rolled (Associated Press, 2005). This occurrence seems to be isolated and patchy (Coral Caye Conservation, 2005). The disturbance on the reef was not intense; therefore the survivability of the coral-associated organisms is not in question. Yet, to consider the tsunami as mild would be a mistake. With all the material and motion in the water, the level of physical disturbance is strong enough to open up competitive grounds for more species on the reef, thereby increasing the biodiversity. The disturbance was not so catastrophic as to totally wipe out the dominant species of the corals and limit the available space to only the most rugged species. With the nutrients and pollutants floating in the water column, many microscopic environments exist for differing organisms to compete for. With different needs and tolerances, the species will begin to dominate their space and have to compete on a larger scale. In any case, biodiversity should initially increase followed by a decrease due to competitive exclusion.

Legislation and Sri Lankan Fisheries

At the turn of the century, Sri Lanka banned the use of coral lime for government building construction (Rajasuriya & White, 1995; Spalding et al., 2000). These actions have not curbed the epidemic of illegal mining off the southern coastlines. These same coasts were where some 30,000 people were killed. Prior to the tsunami, these miners were occasionally arrested, but they were released with a slap on the wrist in the form of a small fine compared to the market potential of the lime. Sri Lanka is also notorious for having politicians stop the legal processing of those arrested (Rajasuriya & Premaratne, 2000). This also affects another law, Fisheries Act of 1996, which tries to manage the exotic fish populations by issuing licenses. The same standard operating procedure exists here. This problem is of grave concern because a larger and larger number of fishermen are entering the industry (Rajasuriya & Premaratne, 2000). This increase in the number of entering fishermen at the turn of the century will be greatly reduced due to the tsunami. Psychological impacts will deter many from this profession. This could lessen the strain on the ecosystem induced by overfishing.

Another problem is that different parts of government manage different sections of the reefs for counterproductive purposes. For example, the Ministry of Industry and Ministry of Fisheries try to facilitate larger fish production. At the same time, the Department of Wildlife Conservation will be trying to increase biodiversity (Weerakody, 2002).

Fisheries Education versus Human Nature

Two main factors are the primary human threats to coral reefs: poverty and a lack of education. Coral reef resources are very limited while the dependence on them by human population is very great. To compound the problem, most reefs are located off the coasts of developing nations where people must have fishing to eat (Tamelander & Obura, 2003). Fish caught for food such as emperors (Lethrinidae), snappers (Lutjanidae), groupers (Serranidae), and goatfishes (Mullidae) are usually consumed on the local level. Aquarium fishes and lobsters are usually exported.

Many fishermen are aware of the effects overfishing can have on local fish populations, but they will simply fish for different species or move locations until they find the fish. For many it is sustenance fishing, bring home fish or go hungry.

Corals are a great natural resource due to the money that can be generated through tourism. Unlike fishing, tourism is sustainable without much investment. "The estimated economic value of coral reefs in Sri Lanka at USD 140,000-7,500,000 per km^2 over a 20-year period" (Berg et al., 1998). People will pay to see the bright colors of the reef and large species of fish. A very stable ecosystem must be in place to support the energy requirements of larger fish like groupers. An environment with illegal lime mining and destructive fishing practices, such as occurs in Sri Lanka, will yield dead corals covered with algae. No one will want to see that, much less pay to do so.

The indigenous people need to understand the market potential of ecotourism. For the Philippines and other island nations, tourism is a major/important economic sector. Over two million people visited the Philippines in 1999 (Ministry of Tourism, 2000). The total revenues generated from tourism in the mid-90's peaked around 2.2 billion USD.

Twenty-five percent of the tourists who visit the islands will engage in some type of reef activity: snorkeling, SCUBA diving, glass bottom boats, and other recreation (Cesar, 2000).

Studies by universities and private organizations require local logistical support in the form of boats, hotels, fuel, and food. Interaction with the local people helps raise awareness if indigenous people are included in conversations and even the studies in the form of boat drivers or whatever else (Perera, 2002). Since the governments apply very little pressure to stop destructive fishing practices, peer pressure and social contempt could expedite the shift toward more eco-friendly fishing industry. An awareness campaign was launched by IUCN. In an eight day exhibit followed up by a mobile exhibition. The exhibition peaked with four-thousand visitors per one day in Tangalle, Sri Lanka. School teachers asked for material on coral reefs to help them to teach the children (IUCN, 2001). Armed by the new curriculum, the next generation of fishermen, who may have to fill the gap left by the generation of fishermen who perished in the tsunami will be much more suited to be good stewards of the corals.

Fisheries Practices that must Change

For 1999, the gross municipal fisheries revenue in the Philippines was approximately 616 million USD (Cesar et al., 1998). Coral reefs are directly related to 15%-30% of the annual total fish production (Murdy & Ferraris, 1980). Sri Lankan fisheries have seen a 65% increase in production over the last decade (Perera et al., 2002). This increase is quite alarming since these fishermen use environmentally unfriendly practices and target around 30 species of fish directly associated with the reef. Bottom-set gill nets and drift gill nets for barracuda. Hook and line fishery is comparatively harmless, but it is practiced on a small scale usually only used for hand-to-mouth subsistence. Bait fish collection methods are less than eco-conscience. Trap fishing and cyanide are some of the more common methods practiced in villages in Sri Lanka (Bently, 1999). Cyanide kills all fish, invertebrates, and corals.

Bottom-set nets for finfish and lobsters are placed directly on the reefs. This type of fishing method is extremely destructive since corals become entangled and torn when the nets are hauled up. The same problem arises with encircling nets. Although, they are not placed directly on the reef structures, they do still get tangled periodically (Perera et al, 2001)

Interviews were carried out two years after El Niño. The interviews revealed that the fishermen were aware of the following: (1) a reduction in lobster abundance in recent years. They are uncertain whether this occurred before or after the bleaching; (2) a noticed decline in catches on the reef and bleaching was recognized as a cause; (3) most believed destructive fishing techniques and a greater number of fishermen were major threats to fish stocks; (4) agreement that barring natural disasters, destructive fishing gear is the main cause of coral degradation; and (5) bottom-set gillnets were identified by the fishermen from Negombo and Kandakuliya as most harmful to corals.

Sadly, the fishermen seem to understand the destruction they are causing and most likely realize their long-term effects. Even though bottom-set gillnets are illegal thanks to the Fisheries Act, fishermen continue to use them because of the income they generate (Perera et al., 2001).

Governments and aid organizations sending capital to the region need to understand that just rebuilding the infrastructure of the fishing industry is only a quick fix. Giving boats and equipment back to the fisheries will only put more stress on the reef. Although fewer fishermen will return, either because of psychological effects or because so many fishermen were killed, the strain will only grow until reefs are destroyed unless current practices are stopped. The governments of most of these nations understand this and are evaluating alternate livelihoods (Weerakody, 2002). The fishermen also show some signs of understanding. The fishermen know that the worst-case scenario for them and the reef would be fisheries obligated and dominated by outside big businesses that put up capital as an investment opportunity and not humanitarian aid. Large scale commercial fishing would be more environmentally and economically devastating.

CONCLUSIONS

The tsunami of 2004 did not destroy the coral reef ecosystems on the scale that was initially reported. Initially, the scientific community predicted that coral mortality would be widespread and algal blooms would soon dominate the reefs. The "fragile" reef communities proved themselves to be quite durable.

Coral reefs will be much better off after the tsunami than before. Much of the human intrusion is gone from the vicinity the reefs. For how long is unknown. Make no mistake, the reef can naturally recover on its own, barring man-made hardships.

I began this thesis in an attempt to understand and report how to best aide the natural pathways of the coral reef ecosystem as it rebuilds. The tolerances of the coral reef ecosystem and the roles of its inhabitants would be better understood. Then the reefs can be more effectively protected from natural and manmade destruction. Evidently, the tolerances of coral reefs are very high against a tsunami. A more major long-term threat to widespread reef damage is human. The natural pathways to recovery will not need to be facilitated. They simply need to be monitored and researched. Between NASA,. NOAA, and the IUCN, educational programs and research has long been underway. The investment in these rare "rainforests of the ocean" are quite sound in the long-term.

Many nations have a great interest in ecotourism (Thailand) and in the occurrences of tsunami. Island nations like Japan and Australia provided some of the first teams gathering data about the tsunami effects (Discovery Times, 2005). Naturally, they have a serious interest in tsunami study.

The long-term advantages and opportunities for the people who live and work on the reefs need to be conveyed. The only way some of these fishing practices and ultimately the degradation of the reef and its associated organisms will stop is with education. Legislation, with its fines and lax enforcement, will most certainly have no effect. With education, the people will demand stiff penalties, more protective legislation, and more enforcement from their governments. The social conscience among coastal citizens will shift to a more conservative mindset. One factor does need to be addressed, poverty. Education is wonderful, but even when the fishermen realized the harm they are inflicting, they continue because fishing is their only means of survival. Most fishermen often live hand-to-mouth and neglect long-term effects. For this reason, alternative livelihoods should be found now while the reefs are still intact.

Many positive aspects have come from the tsunami in the Indian Ocean. First, the world has a second chance to reset the balance between what humans take and what the reef can give. Second, a greater awareness and curiosity has risen about tsunamis and coral reefs. Political opportunities are present. The regions surrounding the Indian Ocean have seen an outpouring of logistical and monetary support. For example, the

United States has not only sent hundreds of millions of dollars ($950M in government funds and $350M in private donations) in aid to the region, but also the U.S.S. Abraham Lincoln and its battle group have implemented its vertical lift component to the relief effort (Discovery Times, 2005). Without these helicopters from the United States and other nations like Australia, many of the inhabitants of these island nations would have been left to die. The U.S. Navy has airlifted food, water, medical supplies and teams to the hardest hit areas. They have also airlifted the dying back out. This humanitarian mission is a much needed facelift for a military that is not very welcome throughout most of the world.

I understand that money is the driving force behind most of the world's problems: global warming from industrialization, clear-cutting for farmland, wars over oil, and coral reef destruction for fishing, to name a few. The world and the nations home to these reefs need to make sure we look long-term in conservation and management. Ecotourism and economic output via the reefs has proven to be tremendous. The shift to alternate livelihoods is paramount if the corals are to survive for future generations.

With most of the world's population taking up residences near oceans, this tsunami has proven itself to be an unforgiving neighbor. On the same note, man has proven himself to be a bad neighbor to the oceans. It is time for change.

It is quite easy to sit in a comfortable room in the richest nation in the world and throw stones about how poorer nations have trounced on coral reefs in an attempt to survive. The responsibility does not rest solely on fishermen, Sri Lankans, Australians, or any one group. As stewards of the land (in this case the sea), everyone needs to be working toward a solution in which these corals can be left alone to be appreciated for their beauty and diversity.

From what I learned in Belize, it seems reef recovery from a tsunami was much less ecologically expensive than from a strong hurricane. In the case of the tsunami, nature wielded a double-edged sword. On one side, it violently reshaped the topography by flooding fields and washing away topsoil with most of these nutrients going to the deep waters. On the other, it protected itself by removing its greatest threat, man. Apparently the reefs dodged not just a bullet, but a nuclear bomb. The energy released by the 2004 tsunami housed 10,000 times more energy than the bomb dropped on Hiroshima (Discovery Science, 2005). Many factors led to the tsunami and the survival of the reef. Most can be attributed to the physics of a wave and the topography. All these factors accumulated so that the human coastal populations are decimated, and the corals and its associated organisms escaped relatively intact considering the amount of energy that they encountered.

Data from the December earthquake and the March earthquake will be analyzed and written about in the years to come. The information is particularly valuable since both earthquakes happened in the same place with tremendous force, and only one produced a tsunami. The 2004 tsunami will serve as the baseline for all the future tsunamis. Science is finally armed with the instruments and data to unlock this phenomenon. The ultimate goal should be tsunami warnings with arrival times and wave heights for an effected area. Presently, the Pacific system is the only one in place. NOAA runs it for the 26 nations encircling the Pacific Ocean. They and Australian geologists knew a tsunami was likely, but they did not know who to call in the Indian Ocean. NOAA and other geology centers walk a fine line (Discovery Science, 2005). The data from these two recent earthquakes should make that line much broader.

There is no warning system in place for the destruction of coral reefs. Perhaps this wakeup call for threat to human lives will awaken us to the destruction of coral reefs as well. Despite the fact that the reefs were damaged less than predicted by the tsunami, reefs globally are dying at an alarming rate (Delay, 2004). I am more aware of that now, and I hope others will awaken to the pending tragedy.

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Appendix I — Catalogue of Fish from Belize Project

Permanent Residents

Permanent Residents	Scientific Name	Family
French Grunt	*Haemulon flavolineatum*	Haemulidae
Blue Striped Grunt	*Haemulon sciurus*	Haemulidae
Dusky Damselfish	*Stegastes adustus*	Pomacentridae
Threespot Damselfish	*Stegastes planifrons*	Pomacentridae
Cocoa Damselfish	*Stegastes variabilis*	Pomacentridae
Bluehead	*Thalassoma bifasciatum*	Labridae
Reef Squirrelfish	*Sargocentron coruscum*	Holocentridae
Neon Goby	*Gobiosoma oceanops*	Gobiidae
Cleaning Goby	*Gobiosoma genie*	Gobiidae

Frequent Visitors

Foureye Butterflyfish	*Chaetodon capistratus*	Chaetodontidae
Blue Tang	*Acanthurus coeruleus*	Acanthuridae
Great Barracuda	*Sphyraena barracuda*	Sphyraenidae
Yellowtail Snapper	*Ocyurus chrysurus*	Lutjanidae
Schoolmaster	*Lutjanus apodus*	Lutjanidae
Stoplight Parrotfish	*Sparisoma viride*	Scaridae
Yellowhead Wrasse	*Halochoeres garnoti*	Labridae
Queen Triggerfish	*Balistes vetula*	Balistidae
Sergeant Major	*Abudefduf saxatilis*	Pomacentridae

Rare Sightings

Gray Angelfish	*Pomacanthus arcuatus*	Pomacanthidae
Spotfin Butterflyfish	*Chaetodon ocellatus*	Chaetodontidae
Graysby	*Cephalopholis cruentatus*	Serranidae
Hogfish	*Lachnolaimus maximus*	Labridae
Slippery Dick	*Halichoeres bivittatus*	Labridae
Trumpetfish	*Aulostomus maculatus*	Aulostomidae
Sand Tilefish	*Malacanthus plumieri*	Malacanthidae
Trunkfish	*Lactophrys trigonus*	Ostraciidae
Yellow Goatfish	*Mulloidichthys martinicus*	Mullidae
Spotted Moray	*Gymnothorax moringa*	Muraenidae
Yellow Stingray	*Urobatis jamaicensis*	Urolophidae
Spotted Eagle Ray	*Aetobatus narinari*	Myliobatidae